60454000 F

049

2.0

(2.1 = H !)

CONTROL DATA CORPORATION

APL
VERSION 2
REFERENCE MANUAL

CDC® OPERATING SYSTEM:
NOS

TABLE OF APL SYMBOLS REFERENCED IN THE TEXT OTHER THAN TABLE C-2

SYMBOL	NAME AND/OR USE	PAGE
+	PLUS	4-2
×	TIMES	4-2
	SIGNUM	4-2
⌈	MAXIMUM	4-2
	CEILING	4-2,4-4
*	POWER	4-2,4-4
	EXPONENTIAL	4-2
|	RESIDUE	4-3,4-5
	MAGNITUDE	4-3
○	CIRCLE	4-3,4-5
	PI TIMES	4-3,4-5
≠	NOT EQUAL	4-3,4-5
<	LESS THAN	4-3,4-5
>	GREATER THAN	4-3
∧	AND	4-3
⍲ (∧~)	NAND	4-3
⍴	RESHAPE	5-3
	SIZE	5-4
[ ]	INDEXING	5-5
	FUNCTION INDEX	3-5
⍳	INDEX OF	6-6
	INDEX GENERATOR	6-6
∈	MEMBERSHIP	6-7
⍋ (Δ|)	GRADE UP	6-8
/	COMPRESS	6-10
	REDUCE	7-1
	CONTEXT EDITING (∇)	2-5
⌿ (/-)	1ST COORD COMPRESS	6-5
	1ST COORD REDUCE	6-5
↑	TAKE	6-12
⌽ (○|)	ROTATE	6-14
	REVERSE	6-14
⊥	BASE VALUE	6-18
⍎ (⊥○)	EXECUTE	6-20
.	DECIMAL POINT	3-3
	GROUP INDICATOR	9-1
R.S	INNER PRODUCT	7-4
⍉ (○\)	TRANSPOSE	6-15
⎕	QUAD (INPUT-OUTPUT)	3-9
	LINE EDITING (∇)	2-4
∇	FUNCTION DEFINITION	SEC 2
→	BRANCH	2-9
⍝ (∩○)	COMMENT	3-2
( )	PARENTHESES	3-6
⋄ (∨∧)	DIAMOND	2-7
A...Z	ALPHABET	3-2
A...Z		
Δ _ Δ		
⍞(OUT)	ESCAPE FROM ⍞ INPUT	2-7
	'' FROM EDITOR (∇)	2-11

SYMBOL	NAME AND/OR USE	PAGE
-	MINUS	4-2
	SUBTRACT	4-2
÷	DIVIDE	4-2
	RECIPROCAL	4-2
⌊	MINIMUM	4-2
	FLOOR	4-2,4-4
⍟ (○*)	LOGARITHM	4-2
	NATURAL LOG	4-2
! (',)	COMBINATIONS	4-3,4-5
	FACTORIAL	4-3
=	EQUAL	4-3,4-5
~	NOT	4-3
≤	NOT GREATER THAN	4-3,4-5
≥	NOT LESS THAN	4-3,4-5
∨	OR	4-3
⍱ (∨~)	NOR	4-3
,	JOIN	6-9
	RAVEL	5-4
⍪ (,-)	1ST COORD JOIN	6-5
⌹ (⎕÷)	MATRIX INVERSE	6-23
	MATRIX DIVIDE	6-24
?	DEAL	6-7
	ROLL	4-3
⍒ (∇|)	GRADE DOWN	6-8
\	EXPAND	6-11
	SCAN	7-3
⍀ (\-)	1ST COORD EXPAND	6-5
	1ST COORD SCAN	6-5
↓	DROP	6-13
⊖ (○-)	1ST COORD ROTATE	6-5
	1ST COORD REVERSE	
⊤	REPRESENT	6-19
⍕ (⊤○)	FORMAT	6-21
∘.S	OUTER PRODUCT	7-4
←	SPECIFY	1-5
⍞ (⎕')	QUOTE QUAD	3-9
⌸ (∇Δ)	BAD CHARACTER	10-11
⍢ (∇~)	DEL TILDE	SEC 2
:	COLON	3-9
;	SEMI-COLON (LISTS)	3-8
'	QUOTE	3-3
$ (S|)	DOLLAR SIGN	C-1
0...9	DIGITS	3-2
Δ	LINE DELETION (∇)	2-4
¯	NEGATIVE	3-3
	BREAK OR ATTN	C-2
¨	DIERESIS	C-1

(Continued on the inside of the back cover)

60454000

CONTROL DATA CORPORATION

APL
VERSION 2
REFERENCE MANUAL

CDC® OPERATING SYSTEM:
NOS

REVISION RECORD	
REVISION	**DESCRIPTION**
A	Manual released.
(9-15-76)	
B	Manual revised to reflect NOS 1.2 at PSR level 460.
(2-10-78)	
C	Manual revised for APL version 2.1 level 472 and NOS 1.3 level 472. The changes include the
(6-13-78)	documentation of the repetition count feature of □FRMT, the FPACK file function, a file storage
	efficiency equation, the workspace SEAL capability, terminal usage under NAM/IAF, and several
	technical corrections.
D	Manual revised to reflect NOS 1.3 at PSR level 477 and to make technical and typographical
(8-18-78)	corrections.
E	Manual revised to reflect NOS 1.4. The changes include the incorporation of new NAM/IAF
(7-20-79)	protocols, a few improvements in notation, and several technical corrections.
F	Manual revised to reflect PSR level 528. The changes include enhancement of FSTATUS to show
(11-31-80)	read failure for coded files, and several technical corrections.
Publication No. 60454000	

REVISION LETTERS I, O, Q AND X ARE NOT USED

Address comments concerning this manual to:

CONTROL DATA CORPORATION
Publications and Graphics Division
215 MOFFETT PARK DRIVE
SUNNYVALE, CALIFORNIA 94086

or use Comment Sheet in the back of this manual

LIST OF EFFECTIVE PAGES

New features, as well as changes, deletions, and additions to information in this manual are indicated by bars in the margins or by a dot near the page number if the entire page is affected. A bar by the page number indicates pagination rather than content has changed.

Page	Revision
Front Cover	-
Inside Front Cover	E
Title Page	-
ii	F
iii	F
iv	F
v	C
vi	C
vii	E
1-1	E
1-2	E
1-3	E
1-4	E
1-5	A
1-6	C
1-7	A
1-8	A
2-1	A
2-2	A
2-3	A
2-4	F
2-5	A
2-6	A
2-7	A
2-8	A
2-9	A
2-10	A
2-11	C
3-1	A
3-2	A
3-3	C
3-4	A
3-5	A
3-6	F
3-7	F
3-8	C
3-9	A
3-10	A
4-1	A
4-2	A
4-3	A
4-4	A
4-5	C
4-6	A
5-1	A
5-2	A
5-3	A
5-4	A
5-5	A
5-6	A
5-7	A
6-1	A
6-2	A
6-3	A
6-4	A
6-5	F
6-6	C
6-7	A

Page	Revision
6-8	A
6-9	A
6-10	A
6-11	E
6-12	E
6-13	A
6-14	A
6-15	C
6-16	A
6-17	A
6-18	A
6-19	A
6-20	C
6-21	A
6-22	B
6-23	C
6-24	A
6-25	A
7-1	A
7-2	A
7-3	A
7-4	A
7-5	A
8-1	A
8-2	C
8-3	C
8-4	C
8-5	C
8-6	E
8-7	E
8-8	C
8-9	C
8-10	C
8-10.1/8-10.2	C
8-11	C
8-12	E
8-13	E
8-14	E
8-15	C
8-16	E
8-17	F
8-18	C
8-19	C
8-20	F
8-20.1/8-20.2	F
8-21	C
8-22	A
8-23	A
8-24	E
9-1	C
9-2	E
9-3	E
9-4	E
9-5	A
10-1	A
10-2	C
10-3	C
10-4	C

Page	Revision
10-5	C
10-6	A
10-7	C
10-8	A
10-9	F
10-10	F
10-11	C
10-12	F
10-12.1/10-12.2	B
10-13	C
10-14	C
10-15	C
10-16	C
10-17	A
10-18	A
11-1	B
11-2	A
11-3	A
12-1	A
12-2	A
12-3	A
12-4	C
12-5	A
12-6	A
13-1	E
13-2	A
13-3	B
13-4	C
13-5	B
13-6	C
A-1	C
A-2	C
A-3	C
A-4	A
A-5	A
A-6	B
A-7	B
B-1	A
C-1	E
C-2	E
C-3	E
C-4	E
C-5	E
C-6	E
C-7	E
C-8	E
C-9	F
C-10	F
C-11	F
D-1	E
D-2	E
D-3	E
D-4	E
E-1	A
F-1	E
F-2	E
F-3	E
Index-1	E
Index-2	E
Index-3	E
Index-4	E
Index-5	E
Index-6	E
Index-7	E
Index-8	E
Index-9	E
Index-10	E
Comment Sheet	E
Inside Back Cover	F
Back Cover	-

PREFACE

This manual describes the APL 2 system, an implementation of the APL language available under the NOS operating system. The APL language had its origins in the book A Programming Language (John Wiley & Sons, New York, 1962) by Kenneth E. Iverson. Because a single line in APL typically expresses what would require many lines in other languages, programs can be written in APL in a fraction of the time with less chance of error. The programs that result tend to be easier to use and easier to extend.

Primary objectives in the design for the APL 2 system were: to achieve a very high level of performance, to provide a flexible file system, to incorporate system functions and variables, to provide all system command capabilities to user-defined functions, and to allow all workspace areas (including the symbol table and file buffers) to change size dynamically according to changing needs. The storage management scheme was designed to anticipate future extensions of APL to allow list structures.

The APL 2 system, formerly named APLUM, was developed under the direction of James H. Burrill at the University Computing Center of the University of Massachusetts. (The APL 2 system accepts files and workspaces produced by the APLUM system with full compatibility.) This manual is a Control Data adaptation of the APLUM Reference Manual (second edition, 1975) by Clark Wiedmann. The following programmers also participated in the APL 2 system development: Rick Mayforth, Sheldon Gersten, Brian Arnold, Jeff Dean, Judy Smith, Bob Weinberger, and Ira Greenberg. In addition, Pat Driscoll and Wendy Mayfield assisted with documentation. Development of APLUM and APL 2 was supported in part by a grant from Control Data Corporation.

Note that this manual is organized as a reference manual, not as a teaching manual. The intent is to accurately describe the APL 2 system, but not to teach APL to the novice. A reader who lacks familiarity with the APL language is advised that it is much easier to learn APL from an introductory text rather than from a reference manual such as this.

The following manuals contain information concerning the NOS operating system:

Control Data Publication	Publication No.
NOS Version 1 Time-Sharing User's Reference Manual	60435500
NOS Version 1 Time-Sharing User's Guide	60436400
NOS Version 1 Reference Manual, Volume 1	60435400
Network Products Interactive Facility Version 1 Reference Manual	60455250
Network Products Interactive Facility Version 1 User's Guide	60455360

This product is intended for use only as described in this document. Control Data cannot be responsible for the proper functioning of undescribed features or parameters.

CONTENTS

Section 1. A Sample Terminal Session

This short introduction to APL shows a sample terminal session from the time of logging on until the time of logging off. This section attempts to emphasize some of the important facilities of APL, and attempts to show the dynamic nature of APL, which may not be evident from the following sections.

LOGGING ON

The first step is to establish a telephone connection between the terminal and the computer. This procedure varies somewhat according to the type of terminal used. Further information about telephone numbers, types of terminals that are supported, passwords, accounting procedures, and restrictions placed on use of computer resources can be obtained from personnel at the computer installation. The following discussion assumes that an acoustic coupler will be used, that NAM/IAF (with auto baud) is used as the communications processor, and that the terminal is an ASCII terminal capable of printing the APL symbols. Terminals not able to print the APL character set can be used, but they are much less satisfactory for program development, although they may be satisfactory for entry of data or transactions. See Appendix C for further information about terminals, and see Appendix F for special instructions for installations not using NAM/IAF.

1. Turn on the terminal and the coupler (sometimes one switch activates both). Dial the phone number for the computer. You should soon hear a high-pitched tone indicating the computer has answered the phone. Place the telephone handset in the acoustic coupler. Usually, one end of the acoustic coupler is marked "cord" to indicate which end of the telephone handset should be placed there. It is important to match the correct ends.

2. When the connection to the computer has been completed, press the RETURN key (possibly labeled CR, CAR RET, or CARRIAGE RETURN). When you press RETURN, the paper should instantly advance two lines. If it does not advance, press RETURN again. After the system responds, type) and press RETURN again. Note that you should be using the APL character set at this point, so the right parenthesis you use is the APL right parenthesis. It should print as a right parenthesis.

3. The system will reply with three lines which appear something like the following

```
76/05/07.   14.12.44.  T1P2047
CDC MULTI-MODE OPERATING SYSTEM          NOS 1.3  485/485
FAMILY:
```

The first line is the current date given in year/month/day and the current time given in hours.minutes.seconds. The second line is the identifying header of the installation which may give the installation name, the operating system, and the version of the operating system. The third line is a request for a family name if the installation has divided its mass storage devices into families. Respond by entering the name of the family to which you are assigned and press RETURN. If your family is the default family name for the system you only need to press RETURN.

The system will then request your user number. If family names are not required, the request for a family name is omitted and the request for a user number is the second line you type in the log-in sequence. This request is:

```
USER NAME:
```

Respond by entering your account name and pressing RETURN.

The system will then reply with:

PASSWORD
****

The second line results from the system overtyping a variety of characters to preserve password security. Type your password over the blackened squares and press RETURN.

4. The system will respond by printing something like:

TERMINAL 332,*NAMIAF*
RECOVER/SYSTEM:

The first line gives the terminal number assigned for this session. The second line invites you to either RECOVER (resume work that was in progress before a line disconnect or system malfunction) or specify the system you wish to use. Type *APL* in response.

APL will respond with something like:

*APL*2.0 76/05/07 16.29.12
APLNEWS 76/05/06
CLEAR WS

The first line identifies the version of the APL system and the date and time when it was created. The message *APLNEWS* indicates when a news item about changes in the APL system was entered. To access news items, type

)*LOAD* **APL*1 *APLNEWS*

The message *CLEAR WS* indicates that you have begun with a clear active workspace.

IMMEDIATE EXECUTION MODE

You can now type APL expressions. What you type is evaluated immediately. For example,

```
      3+5          (You type this and press RETURN.)
8                  (This is the computer's response.)
```

Pressing the RETURN key is your signal to the computer that you have finished typing the line. The computer will not process the line until you press RETURN. The expressions you type are interpreted as they appear on the paper. This is called the principle of visual fidelity. You can space forward or backward as much as you please as long as the final appearance of the paper is what you intended. (Visual fidelity is not preserved on terminals that do not print the APL character set.)

If you make a typing mistake, you can correct the line by canceling the rightmost portion of the line and retyping. On an ASCII terminal you do this by backspacing to the first character to be changed and then pressing LINE FEED (possibly labeled LF on the keyboard). The system responds by printing a pointer below that character and positioning the type element below that pointer. You can then continue typing as if only the symbols to the left of the pointer had previously been entered. To cancel the entire line, hold down the CTRL key while pressing X, then press RETURN.

The following examples show some simple calculations being performed.

```
      2×3
6

      3÷2
1.5
```

Note that the APL system indents six spaces before allowing you to type, but the system prints its response at the left margin. This clearly distinguishes what you type from what the computer types. The following example shows how arithmetic can be performed with several numbers at the same time

```
      2×1 2 3 4
2 4 6 8
```

The series of numbers on the right is called a vector. Each element of the vector was multiplied by 2.

Values can be given a name and saved for later use. The names are called variables. The process of giving a variable a value is called assignment. The following examples show assignment of values to variables *A* and *B*.

```
      A←4.8
      B←1 2 3 4
      A+B
5.8 6.8 7.8 8.8
```

Note that when the result of a calculation is not assigned to a variable it is printed. The sum of the elements in a vector can be found as follows:

```
      B←1 2 3 4
      +/B
10
```

Any symbols on the keyboard can be used as values if they are surrounded by quotes. For example,

```
      GRADES←'ABADCABAABADB'
```

The = symbol can be used to compare values. The result is 1 where a match is found and 0 otherwise. For example,

```
      'A'=GRADES
1 0 1 0 0 1 0 1 1 0 1 0 0
```

The following example shows how a table of comparison values can be produced:

```
      'ABCD'∘.=GRADES
1 0 1 0 0 1 0 1 1 0 1 0 0
0 1 0 0 0 0 1 0 0 1 0 0 1
0 0 0 0 1 0 0 0 0 0 0 0 0
0 0 0 1 0 0 0 0 0 0 0 1 0
```

There is one row for each value in *'ABCD'* and there is one column for each value in *GRADES*. To find the number of *A*'s, *B*'s, *C*'s, and *D*'s, add up the 1's in the four rows as follows:

```
      +/('ABCD'∘.=GRADES)
6 4 1 2
```

Below is an example of another comparison table using ≤ instead of =. Also, instead of using +/ to add the rows as in the last example, +⌿ is used to add up the columns. The symbol ⌿, called an overstrike, is formed by typing /, backspacing, and then typing -. (Actually the two symbols comprising the overstrike can be typed in either order.)

```
      V←2.1 3.2 .08 8.1 4.6 1.2 2.3 4.2 1.6
      2 4 6 8∘.≤V
1 1 0 1 1 0 1 1 0
0 0 0 1 1 0 0 1 0
0 0 0 1 0 0 0 0 0
0 0 0 1 0 0 0 0 0

      +⌿(2 4 6 8∘.≤V)
1 1 0 4 2 0 1 2 0
```

As shown, this operation classifies each value in *V* according to the number of values in 2 4 6 8 it exceeded. That is, a value between 2 and 4 is in class 1, a value between 4 and 6 is in class 2, and a value between 6 and 8 is in class 3. A user defined function can be written to perform this operation:

```
      ∇Z←A CLASSIFY B
[1]   Z←+⌿A∘.≤B∇
```

The first ∇ signals to the computer that you wish to define a function. The first line shows that the function takes two arguments (input values) and gives a result. The computer numbered the next line with [1]. The ∇ at the end indicates you have completed typing the lines of the function. The function can be used as follows:

```
      2 4 6 8 CLASSIFY V
1 1 0 4 2 0 1 2 0
```

Now it might be interesting to tabulate how many 0's, 1's, 2's, and so forth were in the last result. An APL function can be written to do this but it requires two more APL operations: The largest value in a vector *V* is given by ⌈/*V*; and ⍳*N* gives the integers 1, 2 3 ... *N*. We use both of these as follows:

```
      ∇Z←TAB B
[1]   K←⍳((⌈/B)+1)
[2]   K←K-1
[3]   Z←+/(K∘.=B)∇

      TAB 0 1 0 1 2 1 3
2 3 1 1

      TAB(2 4 6 8 CLASSIFY V)
3 3 2 0 1
```

The following function will give a crude histogram of these results:

```
      ∇Z←HIST B
[1]   P←⌈/B
[2]   Z←((P+1)-⍳P)∘.≤B ∇

      HIST 3 3 2 0 1
1 1 0 0 0
1 1 1 0 0
1 1 1 0 1
```

A neater histogram can be produced by adding another line to the *HIST* function:

```
      ∇HIST                (Function definition is opened.)
[3]   Z←' □'[Z+1]          (Another line is added.)
[4]   [□]                  (Display is requested.)
    ∇ Z←HIST B
[1]   P←⌈/B
[2]   Z←((P+1)-⍳P)∘.≤B
[3]   Z←' □'[Z+1]
    ∇
[4]   ∇                    (Definition is closed.)
```

Note that to add more to the function you first type ∇ and the name (but not *Z←HIST B*). The computer numbered the line [3]. Typing [□] on the next line caused the computer to list the function. Finally, the ∇ was typed to indicate that no more lines were to be added. This function can now be used with the two others as follows:

```
      HIST TAB 2 4 6 8 CLASSIFY V
□□
□□□
□□□ □
```

You can display the names of defined functions and variables as shown below:

```
      )FNS
CLASSIFY   HIST   TAB

      )VARS
A   B   GRADES   K   P   V
```

To save the functions and variables for use at some other session, type

```
      )SAVE MYWORK
```

The collection of functions and variables constitutes a workspace. Here a workspace named *MYWORK* was saved. It is advisable to save the workspace often if you are changing it in

order to minimize the amount of work that will be lost in the event of a serious computer malfunction. (See Section 13 for the procedure to follow to avoid losing work after a telephone disconnect or minor computer malfunction.) To remove all functions and variables from the workspace you are now working with, type

```
      )CLEAR
CLEAR WS
      )FNS
                  (No functions.)
      )VARS
                  (No variables.)
```

You can retrieve the *MYWORK* workspace as shown below:

```
      )LOAD MYWORK
MYWORK  75/08/08  16:18:28
      )FNS
CLASSIFY   HIST   TAB
```

To terminate the session and log off the computer, type)*OFF*.

```
      )OFF
A123456   LOG OFF  18.12.07.
A123456   SRU   2.774 UNTS.
```

Although this sample session was short and only used a small fraction of the APL operations, it illustrates how well adapted APL is to experimentation. Programs can easily be developed in small parts and put together to do useful work. The flexibility in using functions in new combinations makes many problems much easier to solve. Many users of APL begin with the habit (formed by familiarity with other computer languages) of writing large monolithic programs in one piece. It should be evident that the modular approach illustrated above is better.

Section 2. User-Defined Functions

Function definition mode allows the user to enter function lines one at a time, remove lines, change lines, insert lines, or display the function. In function definition mode, APL statements entered are not executed or checked for errors, nor are system commands executed. Most errors will be detected when the statement is executed for the first time. System commands are illegal in the body of a function. Table 2.1 contains a summary of function definition.

CREATING A FUNCTION

To enter function definition mode, type ∇ and the function header. The form for the function header should be determined by how the function is used. The six possible forms are shown in the following table.

Number of Arguments	0	1	2
No Result	*name*	*name B*	*A name B*
Result	*Z←name*	*Z←name B*	*Z←A name B*

The name of the function (represented by *name* in the table above) can consist of any number of letters *A* to *Z*, underscored letters *A̲* to *Z̲*, digits 0 to 9, or the symbols _, Δ, or Δ̲, but must not begin with a digit. The function name must not be in use for another global function or global variable. In the table, *Z* is used as the result variable, *A* is the left argument, and *B* is the right argument. Any other names could be used instead, provided they are used consistently in the body of the function. Names of system functions or variables must not be used as the result variable or argument variables.

Table 2-1. Summary of Function Definition.

Creating a function

```
∇Z←A NAME B
```

Reopening definition

```
∇NAME
```

Display

```
[□]     (Display all.)
[□20]   (Display from 20.)
[20□]   (Display line 20.)
```

Insert a line between [2] and [3]

```
[2.1] P←⍳5
```

Delete line [3]

```
[Δ3]
```

Replace line [3]

```
[3] P←Q+5×⍳N
```

Line editing for line [3]

```
        [3□8]              (Line 3, column 8.)
  [3]   P←Q+5×⍳N           (The line is printed.)
          /1   1           (Type / to remove, 1 to insert 1 space.)
  [3]   P←  +5×⍳  N        (Type additions in the spaces.)
```

Extending line [5]

```
[5□0]
```

Context editing for line [3]

```
[3] /.old phrase.new phrase    (To replace.)
[3] /.old phrase.              (To delete.)
[3] /..new text                (To extend.)
[3] /..                        (To display the line and then
                               extend it.)
[3] /.old phrase.new phrase.4  (To replace 4 times beginning at
                               line [3])
[3] /.old phrase.new phrase.10? (Interactive multiple
                                changes.)
[3] /.old phrase.new phrase.V10? (Interactive multiple
                                 replacement of names.)
```

After any of the forms in the table, there can be a semicolon and additional names separated by semicolons. The additional names declare variables and functions to be local to the function. (Local variables and functions are discussed later in this section.)

The function header is line [0] of the function. After entering a ∇ and a header, function definition is said to be open. (If the header contains duplicate names, a DEFN ERROR will occur.) The system then types [1] on the next line to invite the user to enter line [1] of the function. The user can then type function lines, and the system continues to number lines. When the last line has been entered, function definition mode can be terminated by typing a ∇ at the end of a line or on a line by itself. The ∇ is recognized as long as it is the last nonblank character on the line, even if the line is a comment.

Upon an attempt to close definition, statement labels are checked for duplication with names used in the header or names used for labels on other statements. Any errors cause the message *DEFN ERROR* and display of the line with the incorrect label. The error should be corrected, then ∇ should be typed to attempt to close definition again.

REOPENING DEFINITION

To add more lines to a function, first reopen definition by typing ∇ and the name. No other header information should be used--use of other header information causes the system to assume you are mistakenly attempting to create a new function having the same name as an old function. (The header can be changed after definition is open by treating it as line [0] and revising it as described below.) After definition of the function has been opened, the system types the number the next line will have. The user can type additional lines in the same manner as when the function was created.

OVERRIDING THE LINE NUMBER

After the system types a line number, the user can override that line number by providing a different one. For example, assume the system printed [4] because line [4] was expected. The user could type [2] to override the [4] if he wants to enter a new line [2]. He could type the new line [2] on the same line he types the line number, or, he can type only the overriding line number and press RETURN, after which the system would type [2]. After line [2] is provided, the system would continue by numbering the next line with [3].

To insert a new line between lines, use a fractional line number. For example, [3.2] could be used to insert a line between lines 3 and 4. No more than 4 digits are allowed after

the decimal point. The system continues to number subsequent lines by incrementing the last nonzero fractional position of the overriding line number until another overriding line number is used. Thus, after [3.98] would follow [3.99], [4], [4.01], and so forth.

To remove a line, use a request of the form [Δ3]. The delta before the overriding line number indicates that the line should be deleted. More than one line number can be provided (e.g.,[Δ3 9 1.6]). Note that a line cannot be replaced by a blank line by overriding a line number with the number of the line to be deleted and pressing RETURN.

Line [0] (the header) can be replaced like any other line, but it cannot be deleted. If the new line [0] causes the name of the function to change, the old function remains as it was when function definition was opened, and a function having the new name is produced when definition is closed. The function name cannot be changed to the name of a global function or variable, and the function header is not allowed to contain duplicate names.

When function definition is closed, all lines are renumbered with consecutive integers. Because line numbers can change, use of labels for all branching is recommended.

DISPLAY OF FUNCTIONS

When function definition mode is open, the entire function can be displayed by typing [□]. To display only line 3 of the function, type [3□]. To display all lines from line [3] on, type [□3]. If you interrupt the display (see Appendix C), function definition remains open unless a closing ∇ appeared in the same line as the request for display.

LINE EDITING

Line editing can be used to change individual characters in a line. To begin line editing, type something of the form [3□8], where 3 is the number of the line to be revised, and 8 is the approximate position in the line where the first change is to be made. The system then prints the line and unlocks the keyboard below the 8th character. Use spaces or backspaces to position the typeball to the position to be changed. Type / under a character to delete it, or type a digit 1 to 9 to insert 1 to 9 spaces before the character, or type *A* below it to insert 5 spaces, *B* for 10 spaces, *C* for 15 spaces, and so on up to *H* for 40 spaces. To replace a character, you must delete that character (which closes up the line leaving no new space) and type a 1 below the next character to provide space for the

replacement character. After the changes are specified and RETURN is pressed, the system prints the revised line and waits at the position of the first inserted space or at the end of the line if no spaces were inserted. Type in any new characters in the spaces and then press RETURN.

If line editing causes the line number to change, the old line remains intact, and a new line with the new number is inserted. To extend a line, use the form [3□0]. The zero as a position in the line causes the line to be printed and the keyboard to unlock at the end of it.

Note that line editing is not allowed for terminals that do not print the APL character set. Context editing (see below) can be used in these cases.

CONTEXT EDITING

Context editing allows replacement of the first occurrence of a given phrase by another phrase. Context editing is often more convenient than line editing when the changes are localized in a small part of the line and prior display of the line is not required. The editing command has the form

/.old phrase.new phrase.options

The / signals that what follows is a context editing request. The symbol immediately after the / is the symbol chosen by the user to separate the *old phrase* (i.e., that which is to be replaced), the *new phrase* (i.e., the replacement), and the *options*. Any delimiter or series of delimiters at the end of the line can be omitted unless the symbol to the left of the delimiter is a ∇ or a space. In the simplest case where no options are provided, the first occurrence of the *old phrase* is replaced by the *new phrase*. The search for the *old phrase* begins at the left of the line the system is currently expecting but does not continue beyond the end of that line. (A different line number can be specified by overriding the line number provided by the system.) Special cases arise if the *old phrase*, the *new phrase*, or both, are empty. If the *old phrase* is empty, the new phrase is placed at the end of the line; if the new phrase is empty, the old phrase is deleted (i.e., replaced by an empty phrase); if both phrases are empty, the line is displayed and the keyboard unlocks at the end of the line to allow the line to be extended. After a change, except in the case where both phrases are empty, the altered line is displayed. The following examples illustrate cases in which no options are specified:

```
      /.FOUR.SIX      (FOUR is replaced by SIX)
      /,3.5,4.5       (A comma is used as the delimiter
                      because periods occur in the phrase.)
[3]   /.X↓Y+.         (Deletion of X↓Y+; [3] was used to
                      override the line number that had
                      been printed by the system.)
      /..;C           (To extend the line with ;C)
      /..             (To extend the line with information from
                      the keyboard.)
```

The *options* may include a number, question mark, or the letter *V*. These may occur in any order and may have (but do not require) spaces between them. When a number is included in the options, that number is interpreted as a repetition count. The number also has the effect of allowing the search to extend to lines following the line of the function where editing began. After each repetition, the search begins just beyond the last change or match. The operation is repeated until the repetition count is satisfied or until the end of the function is reached.

The question mark can be included among the options if you want to select which matches should result in replacements. The line is shown as it would appear if the change were made, and you are then asked to type *Y* or *N* (for yes or no) to indicate whether the change should be performed.

A *V* among the options stands for variable name replacement. More precisely, the *V* requires that a phrase not be considered a match if it is preceded or followed by a period, letter, or a digit. This option is usually used to prevent accidental matching on part of a name or part of a number. As suggested by use of the letter *V*, this option is usually used to change the names of variables, although it can also be used to control matching of function names, label names, constants, or words in comments or within quotes.

The following examples illustrate the use of these options in various combinations:

```
[6] /.A.J.3V          (Beginning at line [6], replace the first
                      3 occurrences of the variable name A with
                      J.)

[1] /.12.13.?V 1E10   (Change the constant 12 to 13 throughout
                      the function, but allow the user to accept
                      or reject each change. The huge
                      repetition count assures that the entire
                      function will be processed.)
```

```
[4] /,+.×,∘.×,2
```

(Beginning at line [4], change 2 occurrences of +.× to ∘.×. Note the use of commas as delimiters because the phrases contain periods.)

FUNCTION DEFINITION SHORTCUTS

In general, a line you type in function definition mode is used up before you are required to type another line. For example, you can type [3□]∇ to display line [3] and then close function definition. Or, you can type ∇*FN*[3]*P*←⍳*N*∇ to open definition, override the line number with [3], provide a new line [3], and close definition. A ∇ at the end of a statement is always recognized, but other editing requests at the end are interpreted as being part of the line. Hence ∇*FN*[3]*P*←⍳*N*[4□]∇ would cause line [3] to be *P*←⍳*N*[4□]. It would not cause display of line [4] after replacing line [3].

LINE SEPARATOR

You can use the diamond symbol (the overstrike ⋄ for a Selectric terminal) as an input line separator for function definition mode. The parts separated by diamonds are used as if they were entered consecutively from the keyboard except that the normal line number prompt is suppressed. However, input lines for line editing requests must still be entered separately from the keyboard. Any diamonds preceded by an odd number of quotes are considered to be part of character constants and not line separators. If an error occurs, any remaining lines are discarded and input is again requested from the keyboard. The following example shows use of the line separator to define a function and then display it:

```
      ∇Z←NEXTLINE N ⋄ Z←CFREAD N ⋄ Z←(∨\Z≠' ')/Z ⋄ [□]∇
      ∇Z←NEXTLINE N
[1]   Z←CFREAD N
[2]   Z←(∨\Z≠' ')/Z
      ∇
```

The purpose of the line separator is to reduce waiting time when the computer responds slowly. The diamond is allowed as a line separator only in function definition mode and should not be confused with the use of the same symbol in other versions of APL to allow multiple executable APL statements on a line.

ESCAPE FROM FUNCTION DEFINITION

All changes to a function are considered tentative until function definition mode is closed. The overstrike ⍬ (formed from *O*, *U*, and *T*) can be used to escape from function definition mode without changing an old function or creating a new function.

The ∇ is recognized as long as it is the first nonblank (ignoring the system prompt) in a keyboard entry. However, when the system asks you to type *Y* or *N* during interactive context editing, the overstrike ∇ terminates context editing and leaves function definition mode in effect.

LOCALIZATION OF VARIABLES AND FUNCTIONS

The variables local to a function include all variables appearing in the function header and all statement labels. Variables that are not local to any function are called global variables. When execution of a function begins, the local variables take precedence over any other functions and variables having the same names. Other variables that were in effect before this function was called (that is, those not local to this function, which are called variables global to the function) remain accessible. When execution of the function is completed, the variables local to it vanish, thus releasing storage space for other uses, and any variables or functions global to the function become accessible again.

As execution of the function begins, the argument variables are assigned the values of the arguments in the expression invoking the function. If the function modifies the arguments, it is actually changing a copy of the original arguments. (See Section 12 for storage implications.) The label variables are also assigned scalar integer values of the line numbers on which they appear. These variables are locked to prevent them from being assigned inappropriate values. (However, they can be given improper values if they are first erased and then given a value.) The result variable and any other variables listed after the first semicolon in the header have no initial value.

A function can also have another function local to it if it has the second function's name in its header. As for local variables, the local function is undefined as execution of the main function begins. The local function can then be defined by use of □*FX* or □*COPY* with □*ENV* having 1 as its value (the normal case--see Section 8 for details about □*FX*, □*COPY*, and □*ENV*). When execution of the main function completes, the function local to it will vanish, just as a local variable would, and any temporarily inaccessible function or variable having the same name would again become accessible.

FUNCTION EXECUTION

Function execution begins when the name of the function is encountered in an expression being executed and any arguments have been evaluated. The system must save information about how far execution has progressed in the calling line in order to be able to eventually return to it and continue processing. The state indicator is a summary of this information and is available

to the user. Execution of a function begins with establishment of local variables as discussed in the last section. Then, except for branching, the statements are executed in order from first to last. After the last statement has been executed, the value last assigned to the result variable is returned to be used in the calling expression, and all local variables vanish.

Branching can be used to control which statement will be executed next. A branch statement consists of a branch arrow followed by an expression that returns a result. The value must be a scalar or a vector, and unless it is an empty vector, the first value must be a nonnegative integer. If an empty vector is used, the next statement is performed. If the value is a scalar or vector, its first element is used as the number of the line to be executed next. If the value is 0 or exceeds the largest line number, the function exits. The following examples show useful branch statements. Close examination of the expressions to the right of the arrows should show how they generate appropriate line numbers:

```
→5×⍳A<14
```
(Branch to line 5 if *A* is less than 14. Note that this will not work in 0-origin.)

```
→(A=3)/8
```
(Branch if *A* equals 3 to line 8.)

```
→(L1,L2,L3)[2+×B]
```
(Branch to *L1* if *B* is negative, to *L2* if zero, or to *L3* if positive.)

```
→(A>20 18 13 2)/L5,L4,L3,L2
```
(Branch to *L5* if *A* is greater than 20, branch to *L4* if greater than 18 but not 20, to line *L3* if greater than 13 but not 18, to *L2* if greater than 2 but not 13, or go to the next line if *A* is less than or equal to 2.)

STATE INDICATOR

Any lines that call for execution of another function cannot be completed until the other function has exited. Such unfinished lines are called pendent lines. If an error causes a halt at a line of a function, that halted line is said to be suspended. The state indicator is a record of all pendent and suspended lines of functions. It omits partially executed lines entered in immediate execution mode, lines entered for quad input, and lines used as arguments to the execute function. The state indicator with variables, displayed by the system command *)SIV*, shows what lines are pendent or suspended and also shows variables local to functions. An abbreviated form, displayed by the system command *)SI*, omits names of label variables and names appearing in the header after the first semicolon. For example:

```
      )SIV
[3]*Z←PRINT B;X;K:LIMIT:L1:L2
[4] SIMU K:L3

      )SI
[3]*Z←PRINT B
[4] SIMU K
```

In both examples above, the most recently invoked line is shown first. An asterisk marks a line that is suspended. Here, line [4] of *SIMU* called *PRINT*, and execution of *PRINT* halted at line [3] because of an error. The *)SIV* display shows the full function header followed by a colon and names of statement labels separated by colons. If the function has no statement labels, no colons appear.

The *)SIV* display shows that the variable *K* currently accessible is the one local to *PRINT*. The other *K* local to *SIMU* is no longer accessible. However, the label variable *L3* local to *SIMU* still has its value because no variable *L3* is local to *PRINT*. In general, the current value associated with a variable name is that for its first occurrence on the state indicator. If it does not appear on the state indicator, the current value is that of any global variable having that name.

A branch in immediate execution mode can be used to restart execution of the most recent suspended function. For example, →5 would cause execution of *PRINT* to continue at line 5. Usually, the function would be corrected or values of variables would be changed before proceeding. To remove the most recent suspension and the pendent lines that led to it, type a branch arrow with nothing to the right. A beginning user of APL often begins a new execution of a function without removing the old one, causing a large number of suspensions to accumulate. These unnecessary suspensions waste space and can lead to confusion by allowing local variables to make global variables inaccessible. When a suspension occurs, it is a good practice to either make corrections and continue execution or clear the state indicator by use of the niladic branch (see Section 3). An excessive number of suspensions can be eliminated by use of 0 ⎕*SAVE 'name'* (see Section 8).

The information the system keeps about pendent lines can become invalid if the pendent functions are altered, replaced, or erased. The system responds by printing 14: *SI DAMAGE* and surrounding with brackets the names of the affected functions on the state indicator display. Execution of the affected functions cannot be resumed. Experienced users are expected to avoid *SI DAMAGE* if they intend to continue execution of a halted function. Certain changes to suspended functions can also lead to *SI DAMAGE* --specifically, altering the function header or changing the number or relative order of statement labels.

RECURSIVE FUNCTIONS

An APL function may appear more than once on the state indicator and it may even call itself. The following example shows a simple recursive function that calls itself to compute the factorial of an integer:

```
      ∇Z←FACT N
[1]   Z←1
[2]   →(N<2)/0
[3]   Z←N×FACT N-1
[4]   ∇
        FACT 5
120
```

HALTING A FUNCTION

While a function is running, it can be halted by an interrupt (see Appendix C). However, when the keyboard is unlocked, use of the interrupt on some terminals is interpreted as an attempt to revise the line being entered. To halt a function requesting quote-quad input, type the overstrike ⍀ (formed from *O*, *U*, and *T*). This results in suspension as if an error had occurred. To halt a function requesting quad input and remove it and all related pendent lines from the state indicator, use a branch arrow with nothing to the right.

TRACE AND STOP CONTROLS

Any stop, trace, and timing controls in effect for a function are cleared if function definition mode is used to change the function in any way.

LOCKED FUNCTIONS

A function can be locked by using ⍫ (∇ overstruck by ~) in place of ∇ when opening or closing function definition. Locking a function prevents display of the function and prevents its definition from being reopened. An attempt to open definition of a locked function results in the error message *DEFN ERROR*. A locked function cannot be unlocked; if you will want to change a locked function at a later date, keep an unlocked copy of the function in another workspace protected by a password, or keep a printed listing of the function.

Section 3. Statement Form and Order of Evaluation

This section discusses the form of legal APL statements and the order of evaluation of statements. Restricting the discussion to "APL statements" means that system commands (which are distinguished by beginning with a right parenthesis) are not of interest here. The meaning of a statement is determined in part by its form, but mainly by the functions used and the environment in which they are used. This section discusses the influence of form on meaning and leaves the functions and environment to be discussed in several other sections.

SPACES

The use of spaces in an APL statement is usually unimportant to the meaning of the statement except for a few cases:

(1) Names must be separated from other names by spaces, and names must be separated from digits of a number to the right by spaces. (Also, a name beginning with *E* must be separated from digits to the left.) Otherwise, they would run together and appear to be all one name. Conversely, spaces in the middle of a name would make it appear to be two names.

(2) Numbers next to one another must be separated by spaces, and spaces cannot appear within a number.

(3) Spaces within a character constant are treated as any other character in the constant and affect the value of the constant.

(4) Spaces in a comment (except for trailing spaces) are preserved by the system. Although they have no meaning to the APL system, they may be important to the reader of the comment.

FUNCTION DEFINITION AND SYSTEM COMMANDS

As execution begins for statements entered in immediate execution mode, entered in response to quad input, or used as arguments to the execute function (but excluding statements in the body of a function), a check is made to determine if the first nonblank character on the line is ∇, ⍒, or). In these cases the statement is preconverted to become a call to the function ⎕*FD* (a system function that performs function definition mode) or ⎕*SY* (a system function that performs system commands) with the original line as a character argument. For example, ∇*FN*[6⎕] becomes ⎕*FD* '∇*FN*[6⎕]'. To preserve the original meaning, any quotes in the original statement become double quotes after the conversion. Any comment at the end of the original statement becomes part of the argument to ⎕*FD* or ⎕*SY*. The discussion that follows assumes that any such preconversion has already been performed.

COMMENTS

A comment may be entered in immediate execution mode or may appear in a function line. Comments begin with the symbol ⍝ and extend to the right to the last nonblank on the line. The part of the line following the comment symbol is not executed. This allows the user to intersperse descriptive text with APL statements. The following example shows a comment used in immediate execution mode to add a description to the printed transcript of the session:

```
K←2×⍳N ⍝ TO GENERATE 2 4 6, ETC.
```

The following discussion makes no further mention of comments, although a comment may appear at the end of any line, or the comment may constitute the entire line.

CONSTANTS

Constants represent numbers or characters. For example, .14 5.2 9 is a numeric constant-vector, and '*ABCD*' is a character constant-vector. Constants consisting of one character or number are scalars, while those having more components or no components are vectors.

An *unsigned-number* is defined to be any of the following:

digits
digits.digits
.digits

where *digits* represents one or more of the digits 0123456789. The italic notation used here is used throughout this manual to denote a term having a special definition. Here, *digits*

represents a sequence of digits, not the letters *d i g i t* and *s*. Hence the following numbers are examples of *unsigned-numbers*:

```
3.4
.05
58
```

A *number* has any of the following forms:

¯unsigned-number
¯unsigned-number
¯unsigned-number exponent
¯unsigned-number exponent

The symbol ¯ is used to express a negative number--the minus symbol cannot be used in its place. An *exponent* has one of the following forms:

Edigits
E¯digits

The *E* can be read "times 10 to the power." So, 1*E*23 means 1×10*23, and 3.2*E*¯3 is the same as .0032. A *numeric-constant* is formed from one or more *number*, separated by spaces.

A *character-constant* is of the form:

'*symbols*'

where *symbols* represents any number of APL symbols, including no symbols. The symbol ' in a *character-constant* is represented by two quotes. For example,

```
      'IT''S'
IT'S
```

Quotes must always appear in pairs. An expression with an odd number of quotes results in a *SYNTAX ERROR*.

The term *constant* means either a *numeric-constant* or a *character-constant*.

FUNCTIONS

Functions are of three kinds:

(1) System functions, which have names that begin with ⎕ or ⍞, are used to communicate with the APL system.

(2) User-defined functions, which have names formed in the same way as variable names, are the only ones the user can define.

(3) Primitive functions (except those produced by operators) are symbolized by single characters such as +, ×, ÷, etc.

For the purposes of this section, the important features of functions are the number of arguments they require and whether they return results. Functions can be monadic (one argument), dyadic (two arguments), or niladic (no arguments). If *rfunction* is used to denote a function that returns a result and *function* is used to denote one that does not, the six possible forms are:

dyadic-rfunction	(Dyadic, returns a result.)
monadic-rfunction	(Monadic, returns a result.)
niladic-rfunction	(Niladic, returns a result.)
dyadic-function	(Dyadic, no result.)
monadic-function	(Monadic, no result.)
niladic-function	(Niladic, no result.)

For some primitive functions and system functions the same symbol or name is used for two distinct functions--one monadic and the other dyadic. The dyadic function is used if there is a left argument, and the monadic function is used if there is no left argument.

Dyadic user-defined functions can be used without a left argument, but if the function requires a value for its left argument, a *VALUE ERROR* results. The following example is a function that can be used without a left argument provided its right argument is not negative:

```
      ∇Z←A F1 B
[1]   Z←2×B
[2]   →(B≥0)/0
[3]   Z←Z+A ∇

      F1 5
10

      F1 ¯1
05: VALUE ERROR
F1[3] Z←Z+A
          /

      5 F1 ¯1
3
```

The function □*NC*, described in Section 8, can be used to check whether the left argument has a value. This could be used to write user-defined functions that have distinct monadic and dyadic forms in analogy to distinct primitive functions having the same symbol.

Whether a name refers to a function or a variable is a matter that can be decided only when the line begins to execute. Also, whether a function actually returns a result may depend on circumstances. For example, if a user-defined function was defined to return a result, but the result variable was not assigned a value prior to exit from the function, a *VALUE ERROR* results if the expression calling the function requires a result.

OPERATORS

An *operator* is a special kind of function that takes functions as arguments and produces functions as results. Following are examples of four types:

```
A÷.×B   (Inner Product.)
A∘.×B   (Outer Product.)
÷/B     (Reduction.)
÷\B     (Scan.)
```

The operators are the period, /, and \. In place of the ÷ and × in the above examples, any dyadic scalar function symbols could be used. These operators are discussed in detail in Section 7, but for the present, it is important to note that the forms exemplified by ÷.× and ∘.× represent dyadic functions that return results, and ÷/ and ÷\ represent monadic functions that return results.

The axis operator is used to specify the coordinate along which an operation is to be performed. Only a few functions can be used with the axis operator and further details are discussed with those functions. The operator is used in the form *function-symbol*[*value*]. For example:

```
⌽[2]B
÷/[1]B
```

VARIABLES

A *variable* is a name that might be associated with a value. The *variable-name* is formed from any sequence of the letters *A* to *Z*, underscored letters $\underline{A}$ to $\underline{Z}$, digits 0 to 9, or the symbols Δ, $\underline{\Delta}$, or _, but the name cannot begin with a digit. System variables are special variables with names that begin with ⎕ or ⍞. The rest of the name can be composed in the same way as normal variable names. Only the system variables recognized by the system can be used--the user cannot invent new ones.

An *indexed-variable* is of the form:

variable[*list*]

A variable-name having no value associated with it can be used only immediately to the left of an assignment arrow; otherwise a *VALUE ERROR* will result.

VALUES

A value is any of the following:

```
variable
constant
constant[list]
indexed-variable
monadic-rfunction value
left-argument dyadic-rfunction value
niladic-rfunction
niladic-rfunction[list]
left-argument
variable-name←value
indexed-variable←value
(value)
→value
```

The last case has the further restriction that the → may appear only as the first character of a line.

Use of an indexed-variable to the left of a specification arrow sets the values of elements of the variable without changing the shape of the variable. Used elsewhere, the index returns parts of a value.

The assignment arrow can be used to give a value to a variable or to change the value of a variable. The result of the assignment (not to be confused with the value of the variable) is the value used on the right. Consequently, *A*←*B*[1 2]←3 is the same as the two statements *B*[1 2]←3 and *A*←3. Similarly, *A*←□←*B* is the same as □←*B* and *A*←*B*; but *A*←□←*B* is not the same as □←*B* and *A*←□.

The operations to find a value occur in right to left order. Hence, 3×2÷4 means 3×(2÷4). When a dyadic function is encountered, the right argument is preserved while the expression producing the left argument is evaluated. Hence,

```
      A←3
      (A←4)×A
  12
```

More generally, any value encountered in the right to left scan is preserved. For example,

```
      A←4 5 6
      A[3 2 1]←A
      A
  6 5 4
```

(On some APL systems the result would be 4 5 4 or 6 5 6 because the variable on the right is not preserved, while on other systems such operations are prohibited.) However, the following example shows a case where the value is not preserved because the scan has not reached the variable:

```
      A←2
      A+A←3
   6
```

In other words, specification of a variable affects all references to that variable that occur to the left in the line, but affect no references to that variable to the right in the line.

LEFT ARGUMENTS

A left-argument is any of the following:

```
variable
constant
constant[list]
indexed-variable
(value)
(value)[list]
niladic-rfunction
niladic-rfunction[list]
```

For example, 3 can be used as a left argument, *ALPHA* can be used as a left argument, and '123'[2] can be used as a left argument, but 2×3 cannot unless it is enclosed in parentheses. In fact, in 2×3*5, the 3 would actually be used as the left argument to *.

EXPRESSIONS

An expression is the same as a value except that it need not return a result that can be used for subsequent operations. An expression is any of the following:

```
monadic-function value
left-argument dyadic-function value
niladic-function
value
→
```

The last case, called niladic branch, can be used only as the leftmost character of a line. The branch with no value or expression to the right causes exit from the executing function and from all other functions on the state indicator up to any previous suspension.

LISTS

A *list* is of the form:

list-element
list-element;list-element
list-element;list-element;list-element ...

The list, if used for an index, must have one list element for each dimension of the array being indexed.

A *list-element* can be:

vacant
value
expression

An expression that does not give a result can be used in a list used for indexing and is treated as if the list element were *vacant*. A list element is *vacant* if there is nothing at all in that position. For example, *F*[3;] illustrates a list having a *vacant list-element*.

The elements of a list are evaluated in right to left order. Hence

A←3 ; *A*←5

gives *A* a final value of 3. Note that the semicolon is not an APL function. Lists can only be used for indexing, and □*FRMT*. Expressions like the following are illegal:

3ρ(*A*;*B*)

Also, the statement

3ρ*A*;*B*

is equivalent to

(3ρ*A*);*B*

not

3ρ(*A*;*B*)

The expressions separated by semicolons are evaluated separately, then their results constitute the list.

LINES AND IMPLICIT OUTPUT

A *line* is any of the following:

value
expression
list
vacant

When a *line* is a *list*, the list elements are printed in left to right order. The list can contain a mixture of character and numeric values as shown below:

```
      X←34
      'THE VALUE OF X IS: ';X
THE VALUE OF X IS: 34
```

Scalar and vector list elements are printed on the same line (if ⎕*PW* has not been exceeded), but printing of a matrix or array of higher rank begins on a new line, and any subsequent vector or scalar begins on a new line. List elements that are *vacant* or that produce no results are skipped over.

If the first list element is a niladic branch, no output is produced. If the first list element is a branch with a value to the right, the value of the branch is printed along with the other list elements, then the branch is taken.

When the line is a *value*, the *value* is printed unless a specification or branch occurred as the last operation. Hence, `3+2` would print a result, but `A←3+2` or even `(A←3+2)` would not.

STATEMENTS

A *statement* is either a *line* or a *line* with a *label*. The *label* is a *variable-name* and colon placed before the *line*. For example:

```
REPEAT:→4×⍳X=Y
```

A label on a statement entered in immediate execution mode, for quad input, or in the argument to the execute function is ignored.

QUAD AND QUOTE-QUAD

The system variables ⎕ and ⍞ are used for input and output. When they are assigned a value, the system prints the value. When their values are used in an expression, the system reads input from the keyboard to provide the value.

When ⍞ input is requested, the keyboard unlocks (normally with the type element at the left margin). Any characters typed are returned as a vector, except that a single character gives a scalar.

When ⍬ input is requested, the system prints ⍬: and then on the next line indents six spaces and unlocks the keyboard. Any APL expression that returns a result can be entered. If the expression is incorrect or does not produce a result, an error message is printed and the input request is repeated. For example,

```
      A←⍬
⍬:
      B                (This is the input line.)
05: VALUE ERROR
      B
      ⍝
⍬:                     (The input request is repeated.)
      2×⍳4
      A
2 4 6 8
```

A branch in quad input does not actually effect a branch.

The ⍬ can be used for output to conserve lines in a program. The statement ⍬←*A*←*B* has the same effect as the two statements *A*←*B* and ⍬←*B*.

The ⍞ symbol, when used for output, is slightly different from ⍬ used for output. Ordinarily, APL output is followed by a carriage return so that the next input or output will begin on a new line. However, when quote-quad is used for output, the extra carriage return is suppressed. This allows the program to continue output on the same line or to give output and then request input on the same line. For example,

```
      ∇Z←ASK B
[1] ⍞←B
[2] Z←⍞ ∇

      P←ASK 'AGE? '
AGE? 38
      P
  38       (Note leading blanks in the result.)
```

The leading blanks show where the typeball was positioned when the keyboard was unlocked. The person who was typing could have backspaced and replaced the blanks with other characters. Any leading blanks can be removed by using (∨*B*≠' ')/*B*←⍞. Note that ⎕*PW* is not ignored when ⍞ output is used. If the number of printed characters reaches ⎕*PW*, the system inserts a carriage return in the output and indents 6 spaces before continuing the output.

Section 4. Scalar Functions

The class of scalar functions includes those functions that can be defined for scalar arguments and then can be extended to other arguments through element-by-element extension. That is, if the function is monadic, the result has the same dimensions as the argument, and the elements of the result are found by applying the function to all elements of the argument. For the dyadic functions the following rules apply:

1. If the arguments have the same shape, the result has that shape and is formed by applying the function to the corresponding elements of the arguments.

2. If one argument is a one-element array and the other is not, the result has the shape of the one that is not one element. The one-element argument is used with each element of the other argument to form the result.

3. If both arguments are one-element arrays, the result has the larger of the ranks of the arguments.

For the dyadic functions, the arguments must either have identical shapes or at least one must be a one-element array. Any other arguments produce a *RANK ERROR* if their ranks differ, or a *LENGTH ERROR* if their ranks match but dimensions differ. The following examples illustrate some of these rules:

```
      □←A←3 3⍴⍳9
1 2 3
4 5 6
7 8 9

      -A          (A monadic scalar function.)
¯1 ¯2 ¯3
¯4 ¯5 ¯6
¯7 ¯8 ¯9
```

Table 4-1. Summary of Scalar Functions.

Dyadic Function		Monadic Function	
A+*B* Addition	Sum of *A* and *B*. 3+5↔8	+*B* Plus	Same as 0+*B*.
A-*B* Subtraction	*A* minus *B*. 3-4↔¯1	-*B* Additive Inverse	Same as 0-*B*.
A×*B* Times	Product of *A* and *B*. 2×4↔8	×*B* Signum	Sign of *B*. Same as (*B*>0)-*B*<0 ×3 0 ¯2↔1 0 ¯1
A÷*B* Divide	*A* divided by *B*. Division by 0 is not allowed except that 0÷0 is defined to be 1. 3÷2↔1.5	÷*B* Reciprocal	Same as 1÷*B*. Not allowed if *B* is 0. ÷.2↔5
A⌈*B* Maximum	Larger of *A* and *B*. 3⌈5↔5 ¯1⌈¯5↔¯1	⌈*B* Ceiling	If *B* is an integer, the result is that integer. Otherwise the smallest integer greater than *B*. ⌈2.5 3↔3 3
A⌊*B* Minimum	Smaller of *A* and *B*. 3⌊5↔3 ¯1⌊¯5↔¯5	⌊*B* Floor	If *B* is an integer, the result is that integer. Otherwise the largest integer less than *B*. ⌊2.5 3↔2 3
*A**B* Power	*A* to the *B* power. *A* may be zero if *B* is not negative. 0*0 is defined to be 1. If *A*<0, *B* must be representable as a rational fraction with an odd denominator.	**B* Exponential	e to the *B* power (e is 2.71828182845904)
A⍟*B* Logarithm	Base *A* logarithm of *B*. *A* must be positive and must not be 1.	⍟*B* Natural Logarithm	Natural (base e) logarithm of *B*.

Table 4-1. Summary of Scalar Functions, Continued.

A|*B* Residue	The remainder of *B* divided by *A*. More precisely, *B*-*A*×⌊*B*÷*A*+*A*=0	|*B* Magnitude	Absolute Value of *B*. |3 0 ¯3↔3 0 3
A!*B* Combinations of	Number of combinations of *B* things taken *A* at a time for positive integer arguments. More generally *A*!*B* ↔(!*B*)÷(!*A*)×!*B*-*A*	!*B* Factorial	Factorial of *B* for nonnegative integers. Otherwise the mathematical gamma function of *B*+1. Not defined for negative integers.
A○*B* Circular	The argument *A* determines which function from the following table is applied to *B*. *A* must be an integer in the range ¯7 to 7. All angles are in radians.	?*B* Roll	A random choice from ⍳*B*. Depends on current origin.
		~*B* NOT	*B* must consist of 1's or 0's. ~1↔0 ~0↔1
		○*B* Pi times	Pi times *B* ○1↔ 3.14159265358979

N	*N*○*B*	(-*N*)○*B*
0	(1-*B**2)*.5	(1-*B**2)*.5
1	sin *B*	arc sin *B*
2	cos *B*	arc cos *B*
3	tan *B*	arc tan *B*
4	(1+*B**2)*.5	(¯1+*B**2)*.5
5	sinh *B*	arc sinh *B*
6	cosh *B*	arc cosh *B*
7	tanh *B*	arc tanh *B*

A=*B* *A*≠*B* *A*<*B* *A*>*B* *A*≤*B* *A*≥*B*	Equal Not equal Less than Greater than Not greater than Not less than	Result is 1 if the relation holds, 0 otherwise. 3≥5 6 3 1↔0 0 1 1

A∧*B* *A*∨*B* *A*⍲*B* *A*⍱*B*	AND OR NAND NOR	Elements of *A* and *B* must be 1's or 0's. *A*⍲*B*↔~*A*∧*B* *A*⍱*B*↔~*A*∨*B*	*A* 1 0 1 0	*B* 1 1 0 0	*A*∧*B* 1 0 0 0	*A*∨*B* 1 1 1 0	*A*⍲*B* 0 1 1 1	*A*⍱*B* 0 0 0 1

```
      2×A       (Scalar argument and matrix argument.)
 2  4  6
 8 10 12
14 16 18

      A+A       (Two arguments with identical shapes.)
 2  4  6
 8 10 12
14 16 18

      ρ(1 1ρ4)÷(1 1 1ρ3)  (The larger rank prevails.)
 1  1  1
```

Table 4-1 describes most of the scalar functions in complete detail. Most of these functions are familiar mathematical functions or incorporate very simple concepts. Therefore, the discussion below deals with only a few of the less familiar functions or special cases.

The symbol ↔ is used in Table 4-1, as well as in much of the rest of this manual, to mean "is the same as." Note that this symbol is not part of the APL language, but is used to describe APL. When ↔ is used between two expressions, the entire expression to the left is asserted to give the same result as the entire expression to the right.

FLOOR AND CEILING

The functions floor and ceiling always return an exact integer. The result depends on the value of ⎕*CT* as follows: If (|*B*-*NINT B*)≤⎕*CT*×(1+|*NINT B*) the result is *NINT B*, where *NINT B* is the nearest integer to *B*. Otherwise, the result is the least integer larger than *B* for ceiling, or the largest integer smaller than *B* for floor. Note that *B*-⌊*B* can be negative in cases where ⎕*CT* is not zero and *B* is slightly less than an integer.

POWER

In keeping with proper mathematics, the power function does not allow taking square roots of negative numbers (e.g., ¯1*.5), but it does allow taking cube roots of negative numbers (e.g., ¯1*÷3). To distinguish these cases, the power function attempts to represent the right argument *P* as a rational number *N*÷*M*, where *N* is an integer and *M* is the least integer such that (*N*÷*M*)=|*P*. Note that (*N*÷*M*)=|*P* depends on ⎕*CT*. If the left argument is negative and the rational representation has an even denominator, the power function gives a *DOMAIN ERROR*. If the left argument is negative and the rational fraction has an odd denominator, the result is negative if the numerator is odd and is positive if the numerator is even.

RESIDUE

The residue function is slightly more sophisticated than the definition in the table. For example, `2|2-.5×⎕CT` would give the improper negative result `-.5×⎕CT`. The actual algorithm returns zero if `B-A×⌊B÷A+A=0` would give a result having a sign opposite to the sign of `A`.

COMBINATIONS-OF

The combinations-of function returns limit values of `A!B` if `A`, `B`, or `B-A` are negative integers. That is, the result is zero if `A`, `B`, and `B-A` are all negative integers or if `B` is not a negative integer but either `A` or `B-A` is a negative integer. `A!B` is related to the mathematical Beta function as follows:

```
BETA(A,B)←→÷B×(A-1)!A+B-1
```

CIRCULAR FUNCTIONS

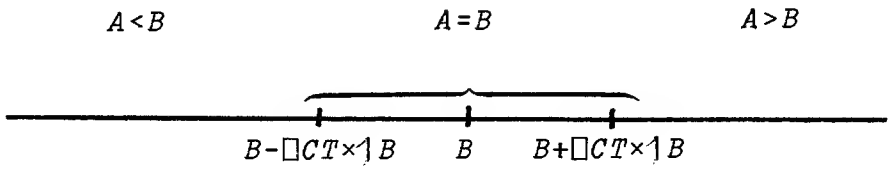
The domains and ranges of the circular functions are given below. All angles are in radians.

N	*N*○*B*	Domain	Range	(-*N*)○*B*	Domain	Range
0	(1-*B**2)*.5	1≥|*B*	(0≤*Z*)∧1≥*Z*			
1	sin *B*		1≥|*Z*	arc sin *B*	1≥|*B*	(○.5)≥|*Z*
2	cos *B*		1≥|*Z*	arc cos *B*	1≥|*B*	(*Z*≥0)∧*Z*≤○1
3	tan *B*			arc tan *B*		(○.5)≥|*Z*
4	(1+*B**2)*.5		1≤*Z*	(¯1+*B**2)*.5	1≤|*B*	0≤*Z*
5	sinh *B*			arc sinh *B*		
6	cosh *B*		1≤*Z*	arc cosh *B*	1≤*B*	0≤*Z*
7	tanh *B*		1≥|*Z*	arc tanh *B*	1≥|*B*	

RELATIONAL FUNCTIONS

The functions = and ≠ are the only scalar functions that can be used with arguments of character type. Characters can be compared with numbers, but the result always shows inequality. For numeric `A` and `B`, the result for `A=B` is 1 if `|B-A` is not greater than `⎕CT×|B`. The three conditions `A<B`, `A=B`, and `A>B` are

always exclusive. For example, if $A=B$ gives 1, then $A>B$ and $A<B$ give 0. The range where two numbers are considered equal is illustrated below:



Note that when B is zero, $A=B$ gives 1 only if A is exactly zero.

Section 5. Array Concepts and Indexing

An APL array can be visualized as an arrangement of values along n orthogonal coordinates, where n is 0 to 75 for this particular APL system. The positions along the coordinates are numbered 1, 2, 3, etc. in 1-origin, and they are numbered 0, 1, 2, etc. in 0-origin. The number of elements along a coordinate can be 0 or more. The lengths of the array along the coordinates are called the dimensions of the array, and the number of coordinates is called the rank of the array. The names scalar, vector, and matrix are used to denote arrays of rank 0, 1, and 2, respectively. No special names exist for arrays of rank greater than 2. The APL system has an arbitrary limit of 75 as the maximum rank of an array, but in practice, this limit is so large that it is not restrictive. Contrary to common casual practice in mathematics, an APL array has a definite rank--a one-element vector is not the same as a scalar, and a matrix with one row or column is not a vector.

The last coordinate of an array is conventionally considered to be the column coordinate, the second from last coordinate is the row coordinate, and the third from last coordinate is the plane coordinate. The following examples show how various arrays can be formed and displayed:

```
      3          (A scalar.)
3

      ⍳4         (A vector.)
1 2 3 4

      2 3⍴⍳6     (A matrix.)
1 2 3
4 5 6

   2 3⍴'ABCDEF'  (A matrix of characters.)
ABC
DEF
```

Table 5-1. Summary of Section 5.

Function	Description
ρ*B* Size	Returns a vector containing the dimensions of *B*. The result has 0 elements for a scalar *B*, 1 element for a vector, and 2 elements for a matrix.
*V*ρ*B* Reshape	Forms a result having the dimensions specified by the left argument and having elements taken from the right argument in odometer order.
,*B* Ravel	The result is a vector containing all elements of *B* in odometer order.
R←*B*[*I*1;*I*2; *I*3; ... ;*IN*] Indexed selection	The result has as dimensions (ρ*I*1),(ρ*I*2),(ρ*I*3), ... ,(ρ*IN*) and contains those elements of *B* for which their first index is in *I*1 and their second index is in *I*2, etc. If a list element is vacant, all possible index values are used.
R[*I*1;*I*2;*I*3; ... ;*IN*]←*B* Indexed specification	The indicated elements of *R* are set to corresponding values from *B*. Either *B* must be a one-element array, or the dimensions of *B* must match (ρ*I*1),(ρ*I*2),(ρ*I*3), ... ,(ρ*IN*) except that dimensions of 1 are ignored. If a list element is vacant, all possible index values are used.

```
      2 3 4ρι24      (Two planes, three rows, four columns.)
 1  2  3  4
 5  6  7  8
 9 10 11 12

13 14 15 16
17 18 19 20
21 22 23 24
```

The last example shows that a rank-3 array is printed as a number of matrices separated by 1 blank line. A rank-4 array would be

printed as a number of rank-3 arrays separated by two blank lines, and in general, a rank-*N* array is displayed as a number of arrays of rank *N*-1 separated by *N*-2 blank lines. An empty array prints as a blank line.

One often visualizes an array as a spatial arrangement of values. The spatial conceptualization leads to use of terms like "shape of array" and "vector along the *K*th coordinate." These terms are important enough to give precise meanings for them. We define the "shape of an array" to be the result given by the size function (to be discussed in this section). As a consequence, a vector and a one-row matrix have different shapes, even though they may be visualized to look the same (and in fact, the system prints them identically). We define "a vector along the *K*th coordinate" to be a vector of those elements in the array for which the coordinates other than the *K*th are the same, and the *I*th element of the vector has *I* as its *K*th coordinate in the array--that is, a line of values aligned in the direction of the *K*th coordinate.

RESHAPE: *R*←*V*ρ*B*

The reshape function was used in some of the previous examples to form arrays. The function forms a result having the dimensions specified by the vector (or scalar) left argument and having elements taken from the right argument. Elements are taken in first to last order, and if they are exhausted, they are used again beginning with the first. The right argument must not be empty unless the result will be empty--"reshape never makes something out of nothing."

ORDERING OF ELEMENTS

The elements of an array are considered to be ordered. The reshape function takes elements according to this ordering. The ordering is the same as the order in which the elements are printed by a terminal. The order is called odometer order because the indices (coordinate positions) vary in the same way as the digits of an odometer. For example, for an array *A*3 having dimensions 2 3 4 the elements in odometer order are:

```
A3[1;1;1]
A3[1;1;2]
A3[1;1;3]
A3[1;1;4]
A3[1;2;1]
A3[1;2;2]
     .
     .
     .
A3[2;3;4]
```

SIZE: $R\leftarrow\rho B$

The size function returns a vector of the dimensions of its right argument. Because there is one element in the result for each dimension of B, the result has 0 elements for a scalar B, 1 element for a vector, 2 elements for a matrix, and so forth. Note that because ρB has one element for each dimension of B, $\rho\rho B$ gives the rank of B as a one-element vector. The following examples illustrate the size function for arrays of various ranks:

```
      ρ3          (A scalar.)
                  (A blank line indicates an empty vector
                  result.)
      ρρ3
0

      ρι3         (A vector.)
3
      ρρι3
1

      ρ2 3ρι6     (A matrix)
2 3
      ρρ2 3ρι6
2

      ρ2 3 5ρι30  (A rank-3 array.)
2 3 5
      ρρ 2 3 5ρι30
3
```

RAVEL: $Z\leftarrow,B$

The ravel function returns a vector result containing all the elements of the right argument in odometer order. For example:

```
      ,2 3ρι6   (Changing a matrix to a vector.)
1 2 3 4 5 6

      ρ,3       (Changing a scalar to a vector.)
1
```

The ravel function can be used to determine the number of elements in an arbitrary array. The number of elements in B is ρ,B. (Note that the ravel function could be omitted in this expression if B were always a vector.)

INDEXED SELECTION: $R\leftarrow B[I1;I2;I3; \ldots ;IN]$

Indexed selection chooses those elements of an array for which all indexes occur in the respective list elements. For example, if M is a matrix, $M[3;4]$ gives the element having 3 as its row index and 4 as its column index. Similarly, $M[2\ 3;4\ 5]$ gives those elements in the second and third rows that are also in the fourth and fifth columns. If a list element is vacant, ιN is used, where N is the length along that coordinate. The index values must be integers in the range of coordinates of elements in B. The index list for an array of rank K must have K-1 semicolons. The result R has the dimensions $(\rho I1),(\rho I2),(\rho I3), \ldots ,(\rho IN)$. Hence the rank of R is the sum of the ranks of the indices. If the indices are vectors, the result satisfies

$$R[K1;K2;K3; \ldots ;KN]=B[I1[K1];I2[K2];I3[K3]; \ldots ;IN[KN]]$$

When the indices are not all vectors, the result is:

$$((\rho I1),(\rho I2),(\rho I3), \ldots ,(\rho IN))\rho B[,I1;,I2;,I3; \ldots ;,IN]$$

Indexed selection cannot be applied to a scalar. The following examples show indexed selection applied to vectors and matrices:

```
      V←3 6 9 12
      V[1]
3
      V[4]
12
      V[5]          (An error results from a request
07: INDEX ERROR      for an element that does not exist.)
V[5]
 /
      V[5;6]        (Because V is a vector, its rank is
06: RANK ERROR       incompatible with the index list.)
V[5;6]
 /

      V[1 2 1 1 2]
3 6 3 3 6

      □←M←3 4ρι12
1  2  3  4
5  6  7  8
9 10 11 12
      M[2;3]
7
      M[2; ]        (Row 2, all columns.)
5 6 7 8
      M[;3]         (All rows, column 3.)
3 7 11
```

```
      M[2;3 4]
7 8

      M[1 2 1;3 1]
3  1
7  5
3  1

      □←K←3 5ρ2 3 2 3 4 2 3 5 3 2 1 3 1 3 1
2 3 2 3 4
2 3 5 3 2
1 3 1 3 1

      ' _|QX'[K]
_|_|Q
_|X|_
  | |
```

(A matrix of characters.)

INDEXED SPECIFICATION: *R*[*I*1;*I*2;*I*3; ... ;*IN*]←*B*

Indexed specification allows setting of selected elements of *R*. The index list indicates elements to be set in the same way as for indexed selection (see previous section). The restrictions on list elements are also the same as for indexed selection. The array *B* must be a scalar (or one-element array) or must have dimensions (ρ*I*1),(ρ*I*2),(ρ*I*3), ... ,(ρ*IN*) except that dimensions of length 1 are ignored in the comparison. If *B* is not a scalar (or one-element array), the elements of *B* are taken in odometer order and placed in appropriate locations in *R*. If two elements of *B* are placed in the same position in *R*, the last one in odometer order in *B* prevails. Both *R* and *B* must be of the same type (i.e., character or numeric). The shape of *R* is not changed by the operation. *R* must not be a scalar.

```
      V←3 6 9
      V[2]←¯1
      V
3  ¯1  9

      V[2 3]←10 12
      V
3  10  12

      V[3 3]←15 16
      V
3  10  16

      □←M←2 3ρ'*'
***
***
```

```
      M[1;1 2 3]←'o'    (A scalar is used repeatedly.)
      M
ooo
***

      M[;1]←'□'         (All rows,  column 1.)
      M
□oo
□**

      M[1;2 3]←'+×'
      M
□+×
□**
```

Section 6. Mixed Functions

The class of mixed functions includes all functions that are not system functions, composite functions, or scalar functions. Because few patterns exist between the mixed functions, they must be discussed individually to describe the arguments they allow and the results they produce. Section 5 already discussed the three mixed functions reshape, size, and ravel. Table 6-1. contains a summary of the mixed functions discussed in this section.

EXCEPTION RULES

Most of the mixed functions have "normal" cases for which the results are relatively simple to express in terms of the arguments. They also generally have additional special cases that are convenient but are treated as exceptions. The following are some of the reasons these exceptions are allowed:

Exceptions to overcome notational difficulty. There is no way to represent an empty numeric vector constant in an expression, and ⍳0 is inconvenient to use as a left argument because it must be surrounded by parentheses. Hence ''⍴*B* is allowed in place of (⍳0)⍴*B*. However, the only other case where an empty character argument is allowed where a nonempty character argument would not be is the catenate function. (However, the system functions ⎕*STOP*, ⎕*TRACE*, and ⎕*LTIME* also allow empty character left arguments.) Another class of exceptions to overcome notational difficulty arises because it is not possible to type a one-element vector constant. Because a constant consisting of a single character or number is a scalar, many functions allow a scalar in place of a one-element vector. However, the left argument for index-of and the arguments to grade up and grade down are not allowed to be scalars.

Table 6-1. Summary of Mixed Functions in Section 6.

Function	Description, Examples
⍳*B* Index generator	Produces a vector of the first *B* integers. ⍳5←→1 2 3 4 5
V⍳*B* Index-of	For each element of *B* gives the first index in the vector *V* where the element is found or 1+⍴*V* (in 1-origin) if the element is absent from *V*. 5 6 7 8⍳6 5 2←→2 1 5
A∈*B* Membership	Returns 1 for each element of *A* that occurs in *B* and returns 0 for other elements of *A*. 1 3 5∈2 3←→0 1 0
S1?*S2* Deal	Chooses *S1* random numbers from ⍳*S2* without any duplications.
⍋*V* Grade up	The *I*th element of the vector result is the index in *V* of the *I*th smallest value in *V*. *V*[⍋*V*] gives *V* sorted in increasing order. ⍋3.3 5.2 1.1←→3 1 2
⍒*V* Grade down	The *I*th element of the vector result is the index in *V* of the *I*th largest value in *V*. *V*[⍒*V*] gives *V* sorted in decreasing order.
A,[*K*]*B* Join	Joins *A* and *B* along the *K*th coordinate. 1 2 3,4 5←→ 1 2 3 4 5
V/[*K*]*B* Compress	The result includes elements along the *K*th coordinate of *B* for which there are corresponding 1's in *V* and does not include elements for which there are 0's in *V*. 1 0 1/1 2 3←→1 3 1 0 1/'*ABC*'←→'*AC*'

Table 6-1. Summary of Mixed Functions in Section 6, Continued.

Function	Description, Examples
V\[*K*]*B* Expand	Expands by inserting zeros (if *B* is numeric) or blanks (if *B* is of character type) where there are 0's in *V* and selects consecutive elements along the *K*th coordinate of *B* where there are 1's in *V*. 1 0 1 0\3 4↔3 0 4 0 1 0 1\'*AB*'↔'*A B*'
A↑*B* Take	Selects the first (if *A*[*K*]>0) or last (if *A*[*K*]<0) |*A*[*K*] elements along the *K*th coordinate of *B*. If |*A*[*K*] exceeds (ρ*B*)[*K*], zeros or blanks are used as the extra elements. 3↑1 2 3 4 5↔1 2 3 ¯3↑'*ABCDE*'↔'*CDE*' 4↑1 2↔1 2 0 0
A↓*B* Drop	Drops the first (if *A*[*K*]>0) or last (if *A*[*K*]<0) |*A*[*K*] elements along the *K*th coordinate of *B*. If |*A*[*K*] exceeds (ρ*B*)[*K*], the *K*th dimension of the result is zero. 3↓1 2 3 4 5↔4 5 ¯3↓'*ABCDE*'↔'*AB*'
⌽[*K*]*B* Reverse	Reverses the order of elements along the *K*th coordinate of *B*. ⌽5 6 7↔7 6 5 ⌽'*ABCD*'↔'*DCBA*'
A⌽[*K*]*B* Rotate	Shifts vectors along the *K*th coordinate of *B* in a negative direction (for *A*>0) or positive direction (for *A*<0). 2⌽1 2 3 4 5↔3 4 5 1 2 ¯2⌽'*ABCDE*'↔'*DEABC*'
⍉*B* Monadic transpose	Reverses coordinates of *B*. ρ⍉*B*↔⌽ρ*B*
A⍉*B* Dyadic transpose	Interchanges coordinates of *B* according to *A*. The *K*th coordinate of the result corresponds to the (*A*=*K*)/⍳ρ*A* coordinate of *B*.

Table 6-1. Summary of Mixed Functions in Section 6, Continued.

Function	Description, Examples
A⊥*B* Base value	Evaluates *B* as a number represented in a number system having radices *A*. 2 2 2⊥1 0 1←→5 10 10 10⊥2 3 4←→234
A⊤*B* Represent	Represents *B* in the number system having radices *A*. 2 2 2⊤5←→1 0 1 10 10 10⊤296←→2 9 6
⍎*B* Execute	Executes the character vector *B* as an APL statement. ⍎ '⍳5'←→1 2 3 4 5
⍕*B* Monadic format	Produces a character array representation of *B*. Except for treatment of lines longer than ⎕*PW*, ⍕*B* looks exactly like *B* when printed.
A⍕*B* Dyadic format	Represents columns of *B* according to the format specified by pairs of numbers in *A*. The first element of a pair in *A* is the width of the field (0 to have the system choose a width), and the second element of the pair gives the number of digits beyond the decimal if positive. If the second element of the pair is negative, its absolute value determines the total number of digits, and exponential format is used.
⌹*B* Matrix inverse	Matrix inverse of *B*. Same as *I*⌹*B* where *I* is an identity matrix.
A⌹*B* Matrix divide	Solution to a system of equations (for a square matrix *B*) or least squares regression coefficients (if *B* has more rows than columns). Same as (⌹*B*)+.×*A*.

Exceptions to ignore dimensions of 1. At times it is convenient to treat a row or column of an array as a vector, while at other times it is more convenient to treat it as a matrix. Consequently, some flexibility has been built into functions to allow extra or missing dimensions of 1.

Generalized scalar extension. The dyadic scalar functions allow a scalar argument to be used repeatedly with all elements of the other argument. More generally, some mixed functions allow a single vector, plane, etc. to be used repeatedly with parts of the other argument.

ARRAY TYPES

An array, even if it is empty, is either of character type or numeric type. Those mixed functions that rearrange elements of an array or select elements of an array always return a result having the same type as the right argument. For example, 0⍴'*ABCD*' gives an empty result of character type.

AXIS OPERATOR

For several of the mixed functions (and composite functions) an axis operator can be used to specify the coordinate along which the operation is to be performed. If no axis is specified, the last coordinate is assumed. Alternate symbols can be used to perform the operations along the first coordinate. These forms are:

Last coordinate	First coordinate	Kth coordinate
A,*B*	*A*⍪*B*	*A*,[*K*]*B*
A⌿*B*	*A*⍀*B*	*A*⌿[*K*]*B*
A⍀*B*	*A*⌽*B*	*A*⍀[*K*]*B*
⌽*B*	⊖*B*	⌽[*K*]*B*
A⌽*B*	*A*⊖*B*	*A*⌽[*K*]*B*

Note that the symbols for performing the operations along the first coordinate are not allowed to be used with an axis operator. For example, ⊖[*K*]*B* would produce a *SYNTAX ERROR*.

The value used for an axis operator must be a one-element array, and for functions other than join, it must be an integer in ⍳⍴⍴*B* (except that if *B* is a scalar, it may be ⎕*IO*). For the join function (e.g., *A*,[*K*]*B*) the value of *K* should be an integer in ⍳(⍴⍴*A*)⌈(⍴⍴*B*)⌈1 or any half integer obtained by adding or subtracting .5 from one of those integers.

INDEX GENERATOR: *R*←⍳*B*

The index generator function produces a vector of length *B* containing the first *B* integers. The result depends on the current origin.

Requirements for *B*. *B* must be a one-element array containing a nonnegative integer.

Examples.

```
      ⍳3    (In 1-origin.)
1 2 3

      ⎕IO←0
      ⍳5
0 1 2 3 4    (In 0-origin.)

      ⍳0
        (Blank line indicates ⍳0 is empty.)
```

INDEX-OF: *R*←*V*⍳*B*

The index-of function returns for each element of *B* the least index *I* in the vector *V* for which *V*[*I*] equals the element of *B*. If no value in *V* is equal, the result element is 1+⍴*V* in 1-origin, or ⍴*V* in 0-origin. When *V* and *B* are numeric, the comparisons use ⎕*CT* so that elements of *V* and *B* may be considered equal even if they differ slightly.

Requirements for *V* and *B*. *V* must be a vector--a scalar is not allowed. *B* may be of any shape and the result will have that shape.

Examples.

```
      4 5 6⍳2 5
4 2

      ⎕←M←2 3⍴ 'DEFGHI'
DEF
GHI

      'HIDE DOG'⍳M
3 4 9        (A matrix result for a matrix right argument.)
8 1 2

      7 8 9⍳'AB'
4 4          (Characters never equal numbers.)
```

```
      'ABA'⍳'ABAB'
1 2 1 2

      ⎕IO←0
      'ABA'⍳'ABAB'
0 1 0 1       (The 0-origin result is 1 less.)
```

MEMBERSHIP: *R*←*A*∈*B*

The membership function returns 1 for each element of *A* that occurs in *B*. For numeric arguments the comparisons use the current value of ⎕*CT*, so values may differ slightly and still be considered equal.

Requirements for *A* and *B*. *A* and *B* may have any shape. The result has the same shape as *A*.

Examples.

```
      1 2 3∈3 1 6 4 9
1 0 1

      'ABCD'∈'BACKS'
1 1 1 0

      ⎕←A←2 3⍴'CATDOG'
CAT
DOG

      A∈'GOAT'
0 1 1
0 1 1  (The result has the shape of the left argument.)

      'GOAT'∈A
1 1 1 1

      'ABC'∈1 2 3 4
0 0 0
```

DEAL: *R*←*S*1?*S*2

The deal function chooses at random *S*1 values from ⍳*S*2 without repetitions.

Requirements for *S*1 and *S*2. Both *S*1 and *S*2 must be one-element arrays containing nonnegative integers such that *S*1≤*S*2. The result is a vector of length *S*1.

Examples.

```
      3?5
  3 1 4

      3?5
  4 5 3

      5?5
  1 2 5 3 4

      ⎕IO←0
      5?5
  3 2 0 1 4    (0-origin.)
```

GRADE UP AND GRADE DOWN: *R*←⍋*B* and *R*←⍒*B*

The *I*th element of the vector result *R* is the index in *B* where the *I*th smallest (for grade up) or the *I*th largest (for grade down) element of *B* occurs. The comparisons do not use ⎕*CT*. If a value occurs more than once in *B*, the indices of those values occur together in *R* in increasing order.

Requirements for *B*. *B* must be a numeric vector. The result *R* is a numeric vector of the same length as *B*.

Examples.

```
      ⍋3.3 1.1 2.2 4.4 1.1 5.5
  2 5 3 1 4 6

      ⍒3.3 1.1 2.2 4.4 1.1 5.5
  6 4 1 3 2 5

      V←3.3 1.1 2.2 4.4 1.1 5.5
      V[⍋V]  (To sort in increasing order.)
1.1 1.1 2.2 3.3 4.4 5.5

      V[⍒V]   (To sort in decreasing order.)
5.5 4.4 3.3 2.2 1.1 1.1

      P←3 4 5 1 2
      ('ABCDE'[P])[⍋P] (⍋P is the inverse of a permutation
ABCDE                   vector P.)


      X←'ABC'
      Y←'DEF'
      Z←'GHI'
      (X,Y,Z)[⍋⍋ 0 2 1 1 2 0 0 2 1]
AGDEHBCIF    (Select next from X for a 0, Y for a 1,
             Z for a 2.)
```

```
      ⎕IO←0
      ⌊3.3 1.1 2.2
1 2 0          (0-origin.)
```

JOIN: *R*←*A*,[*K*]*B*

The join function connects *A* and *B* along a coordinate already existing in *A* or *B* or along a new coordinate of length 1 inserted into each. The first elements along the coordinate come from *A* and the rest come from *B*. When *K* is an integer, the operation is called catenate. When *K* is not an integer, the operation is called laminate and the new coordinate of length 1 is inserted into each argument between the existing ⌊*K* coordinate and ⌈*K* coordinate.

Requirements for *A* and *B*. Except for the special cases below, *A* and *B* must have the same rank, and dimensions other than the *K*th must be the same; that is, (*K*≠⍳⍴⍴*A*)/⍴*A* and (*K*≠⍳⍴⍴*B*)/⍴*B* must be the same. The types of *A* and *B* must be the same unless one or both are empty arrays. (Warning: some APL systems do not allow empty arrays to have a different type. It is recommended that differing types be avoided for compatibility.) The shape of the result is the same as the shape of the two arguments except that the *K*th coordinate of the result is (⍴*A*)[*K*]+(⍴*B*)[*K*]. If both arguments are empty and of differing types, the result is numeric.

Exception cases. If *A* or *B* is a scalar (but not both), it is reshaped to have the shape of the other argument except that the *K*th dimension is 1 for catenate. If both arguments are scalars, they are treated as one-element vectors for catenate. For catenate, one argument may have a rank 1 less than the rank of the other argument. In this case a new coordinate of length 1 is inserted to become the *K*th.

Examples

```
      1 2 3,4 5 6     (Joining two vectors.)
1 2 3 4 5 6

      ⎕←M←2 3⍴'*'
***
***

      ⎕←N←3 3⍴'o'
ooo
ooo
ooo

      M,[1]N
***
***
ooo
ooo
ooo
```

```
      □←L←2 4ρ'□'
□□□□
□□□□

      M,L
***□□□□
***□□□□

      M,'+'
***+
***+
```

(The scalar is treated as a one-column matrix.)

```
      M,'34'
***3
***4
```

(A vector is treated as a one-column matrix.)

```
      M,[1]'345'
***
***
345
```

(A vector is treated as a one-row matrix.)

```
      1 2 3,[.5]4 5 6
1 2 3
4 5 6
```

(Laminate along a new first coordinate.)

```
      1 2 3,[1.5]4 5 6
1 4
2 5
3 6
```

(Laminate along a new last coordinate.)

```
      1 2 3,[1.5]4
1 4
2 4
3 4
```

COMPRESS: $R←V/[K]B$

The compress function shortens B along the Kth coordinate by omitting those elements for which there are corresponding 0's in V.

Requirements for V and B. V must be a vector and all elements of V must be 1's or 0's. The length of V must be the same as $(\rho B)[K]$. The result has the same dimensions as B except that the Kth dimension is $+/V$.

Exception cases. If V or B is a scalar it is treated as a one-element vector. Then if V is a one-element vector, it is extended to the length of B along the Kth coordinate. If B is a one-element vector, it is extended to the length of V.

Examples.

```
      1 0 1 0 1/1 2 3 4 5
1 3 5

      1 0 1 0 1/'ABCDE'
ACE

      1/'ABCDE'
ABCDE

      0/'ABCDE'
```

(Blank line indicates an empty result.)

```
      □←M←3 4⍴⍳12
1  2  3  4
5  6  7  8
9 10 11 12

      1 0 1 1/M
1  3  4
5  7  8
9 11 12

      1 0 1/[1]M
```

(Same as 1 0 1⌿M.)

```
1  2  3  4
9 10 11 12

      1 0 1/4
4 4

      ⍴1/2
1
```

(Scalar right argument, but vector result.)

EXPAND: R←V\[K]B

The result is formed by expanding B along the Kth coordinate by filling with zeros (if B is numeric) or blanks (if B is of character type) in those positions in R for which there are corresponding 0's in V.

Requirements for V and B. Ignoring the special cases, V must be a vector containing only 1's and 0's such that (+/V)=(⍴B)[K]. The result R has the same dimensions as B except that the Kth dimension is ⍴V.

Exception cases. If V or B is a scalar, it is treated as a one-element vector.

Examples.

```
      1 0 1 0 1\1 2 3
1 0 2 0 3

      □←M←2 3⍴⍳6
1 2 3
4 5 6

      1 0 1 0 1\M
1 0 2 0 3
4 0 5 0 6

      1 0 1\[1]M   (Same as 1 0 1\M.)
1 2 3
0 0 0
4 5 6

      ⍴1\2
1                  (A vector result.)

      ' '=0\''     (An empty array can be expanded.)
1

      0\⍳0
0
```

TAKE: *R*←*V*↑*B*

The take function selects |*V*[*K*] first elements (for *V*[*K*]>0) or last elements (for *V*[*K*]<0) along the *K*th coordinate of *B*. If |*V*[*K*] exceeds (⍴*B*)[*K*], zeros (if *B* is numeric) or blanks (if *B* is of character type) are used to provide the extra elements.

Requirements for *V* and *B*. Ignoring the special cases below, *V* must be a vector having an integer for each dimension of *B*. That is, (⍴*V*)=⍴⍴*B*. The result *R* has dimensions |*V*.

Special cases. If *V* is a scalar, it is treated as a one-element vector. If *B* is a scalar, it is treated as a one-element array of rank ⍴*V*.

Examples.

```
      3↑1 2 3 4 5
1 2 3

      ¯3↑1 2 3 4 5
3 4 5

      3↑'ABCDE'
ABC
```

```
      5↑1 2 3
1 2 3 0 0

      □←M←3 4⍴⍳12
1  2  3  4
5  6  7  8
9 10 11 12

      2 ¯5↑M (First 2 rows, last 5 columns.)
0 1 2 3 4
0 5 6 7 8

      3↑⍳0    (Take can be applied to an empty array.)
0 0 0

      2 3↑5   (5 is treated as a 1 by 1 matrix.)
5 0 0
0 0 0
```

DROP: *R*←*V*↓*B*

The drop function forms its result by omitting |*V*[*K*] first elements (if *V*[*K*]>0) or last elements (if *V*[*K*]<0) along the *K*th coordinate of *B*.

Requirements for *V* and *B*. Ignoring the special cases below, *V* must be a vector of integers, and ⍴*V* must be the same as ⍴⍴*B*. The result has dimensions 0⌈(⍴*B*)-|*V*.

Special cases. If *V* is a scalar, it is treated as a one-element vector. If *B* is a scalar, it is treated as a one-element array of rank ⍴*V*.

Examples.

```
      3↓1 2 3 4 5
4 5

      ¯2↓'ABCDEF'
ABCD

      10↓1 2 3
          (Blank line indicates an empty result.)

      □←M←3 4⍴⍳12
1  2  3  4
5  6  7  8
9 10 11 12

      1 ¯2 ↓M(First row and last 2 columns are dropped.)
5  6
9 10
```

```
      ρ0 0⍴3
1 1          (The scalar was treated as a matrix.)

      (⍳0)⍴3
3
```

REVERSE: *R*←⌽[*K*]*B*

The reverse function reverses the order of elements along the *K*th coordinate of *B*. The result has exactly the same shape as *B*.

Examples.

```
      ⌽ 3 4 5 6
6 5 4 3

      ⌽'ABCDEF'
FEDCBA

      □←M←3 4⍴⍳12
1  2  3  4
5  6  7  8
9 10 11 12

      ⌽M
 4  3  2  1
 8  7  6  5
12 11 10  9

      ⊖M      (Same as ⌽[1]M.)
9 10 11 12
5  6  7  8
1  2  3  4
```

ROTATE: *R*←*A*⌽[*K*]*B*

The rotate function shifts elements of *B* along the *K*th coordinate a number of positions specified by *A*. For positive elements of *A*, the elements move so that their indices decrease, and for negative elements of *A* their indices increase. Elements shifted beyond the end are replaced at the other end. The absolute value of the elements in *A* gives the number of positions the corresponding vector along the *K*th coordinate of *B* is shifted.

Requirements for *A* and *B*. Ignoring the exceptions below, *A* must have one element for each vector in *B* along the *K*th coordinate. That is, ⍴*A* must be (*K*≠⍳⍴⍴*B*)/⍴*B*. Thus the dimensions of *A* must be like those of *B* except that the *K*th dimension of *B* is absent from *A*. The result has the same shape as *B*.

Special cases. If *A* is a scalar, it is extended to become an array having dimensions suitable for *B*. Rotation of a scalar is allowed, but the left argument must be a scalar, and the result is the same as *B*. When the right argument is a vector or a scalar, the left argument may be either a scalar or a one-element vector.

Examples.

```
      2 ⌽ 1 2 3 4 5 (Rotation by 2 positions to the left.)
3 4 5 1 2

      ¯2 ⌽ 1 2 3 4 5(Rotation by 2 positions to the right.)
4 5 1 2 3

      2 ⌽'ABCDE'
CDEAB

      ⎕←B←3 4⍴⍳12
1  2  3  4
5  6  7  8
9 10 11 12

      0 ¯1 2 ⌽ B
 1  2  3  4        (Rows are shifted.)
 8  5  6  7
11 12  9 10

      0 ¯1 1 2 ⊖B (Same as 0 ¯1 1 2 ⌽[1]B.)
1 10  7 12
5  2 11  4
9  6  3  8

      1 ⌽ B
 2  3  4 1
 6  7  8 5
10 11 12 9     (All rows are shifted by 1.)
```

MONADIC TRANSPOSE: *R*←⍉*B*

The monadic transpose function reverses the coordinates in *B*. Thus the last coordinate in *R* corresponds to the first in *B*, the second to the last corresponds to the second in *B*, and so forth. For a vector or scalar, the result is the same as the argument. For a matrix, the result is the usual matrix transpose. For an array of rank 3, *R*[*I*;*J*;*K*] is the same as *B*[*K*;*J*;*I*]. The shape of the result is ⌽⍴*B*.

Examples.

```
      ⎕←M←3 4⍴⍳12
1  2  3  4
5  6  7  8
9 10 11 12
```

```
      ⍉M
1  5  9
2  6 10
3  7 11
4  8 12

      □←C←3 4⍴'FOURFIVEFORT'
FOUR
FIVE
FORT

      ⍉C
FFF
OIO
URR
RET

      □←R3←2 3 4⍴⍳24
 1  2  3  4
 5  6  7  8
 9 10 11 12

13 14 15 16
17 18 19 20
21 22 23 24

      ⍴⍉R3
4 3 2

      ⍉R3
 1 13
 5 17
 9 21

 2 14
 6 18
10 22

 3 15
 7 19
11 23

 4 16
 8 20
12 24
```

DYADIC TRANSPOSE: *R←V⍉B*

The dyadic transpose function interchanges coordinates of *B* according to the integer values in the vector *V*.

Requirements for *V* and *B*. Ignoring the special case below, *V* must be a vector having one element for each dimension of *B*--that is, *V* and *B* must satisfy $(\rho V)=\rho\rho B$. The elements must be integers such that $(\iota\lceil/V)\in V$ and $V\in\iota\lceil/V$ (all integers up to the largest element in *V* but no other values). The rank of *R* is $\lceil/V$ in 1-origin or $1+\lceil/V$ in 0-origin. The *I*th dimension of *R* is $\lfloor/(V=I)/\rho B$. The *I*th coordinate of *B* becomes the *V*[*I*]th coordinate of *R*. If two or more coordinates of *B* map into the same coordinate of *R*, the length along that coordinate is the least of the related dimensions in *B*.

Special case. If *V* is a scalar, it is treated as a one-element vector.

Examples.

```
      □←M←3 4ρ'ABCDEFGHIJKL'
ABCD
EFGH
IJKL

      2 1 ⍉ M
AEI
BFJ
CGK          (R[I;J]=B[J;I].)
DHL

      1 1⍉M  (R[I]=B[I;I]. The diagonal of the matrix.
AFK           Note that the length is the shorter
              of the two dimensions of the matrix.)

      □←B←2 3 4ρ⍳24
 1  2  3  4
 5  6  7  8
 9 10 11 12

13 14 15 16
17 18 19 20
21 22 23 24

      2 1 3 ⍉ B
 1  2  3  4
13 14 15 16

 5  6  7  8  (R[I;J;K]=B[J;I;K].)
17 18 19 20

 9 10 11 12
21 22 23 24
```

```
      1 1 1⍉B
1  18          (R[I]=B[I;I;I]. The main diagonal.)

      1 2 1⍉B
 1  5  9
14 18 22       (R[I;J]=B[I;J;I]. A diagonal slice.)

      2 1 2⍉B  (R[I;J]=B[J;I;J].)
1  14
5  18
9  22
```

The expressions to the right which relate elements of *B*, *V*, and *R* are formed as follows: The indices applied to *R* are (⌈/*V*)⍴'*IJKL...*', and the indices applied to *B* are '*IJKL...*'[*V*].

BASE VALUE: *R*←*A*⊥*B*

The base value function evaluates its right argument as a representation of a number in a general number system described by its left argument. For example, `2 2 2⊥1 0 1` gives `5`; the vector `1 0 1` is evaluated as a number represented in base 2. The left argument, `2 2 2`, contains the radices of the number system. (Radices are ratios between the weightings of the positions.) For the simple case of a vector left argument *A*, the *K*th weighting (in 0-origin) is ×/(-*K*)↑*A*. That is, the *K*th weighting is the product of the last *K* elements of *A*. If *W* is a vector of these weightings, the result for *A*⊥*B* is *W*+.×*B*. Thus for the case `2 2 2⊥1 0 1` the result is `+/4 2 1×1 0 1`.

Requirements for *A* and *B*. Except for the special cases below, *A* and *B* must satisfy (¯1↑⍴*A*)=1↑⍴*B* (the last dimension of *A* must be the same as the first dimension of *B*). For arrays *A* and *B*, the vectors along the last coordinate of *A* are used to find vectors of weightings, and each vector along the first coordinate of *B* is evaluated according to each vector of weightings. The weightings are *W*←⌽×\(⍴*A*)↑⌽*A*,1. The result is then *W*+.×*B*. The result has as dimensions (¯1↓⍴*A*),1↓⍴*B* (same as the dimensions of *A*+.×*B*).

Special cases. If *A* or *B* is a scalar, it is treated as a one-element vector. If the last dimension of *A* does not match the first dimension of *B* but one of the two dimensions is 1, that dimension is extended to match the other.

Examples.

```
      24 60 60⊥1 2 3
3723                 (One hour, two minutes, and
                      3 seconds is 3723 seconds.)
```

```
      0 60 60⊥1 2 3 (The first element in the
3723                  left argument has no effect.)

      □←A←2 3⍴2 2 2 10 10 10
 2  2  2
10 10 10

      □←B←3 4⍴1 1 3 2 0 1 4 0 1 0 5 3
1 1 3 2
0 1 4 0
1 0 5 3

      A⊥B             (Each vector along the first coordinate of B
  5   6  25  11        is evaluated according to each vector
101 110 345 203       along the last coordinate of A.)

      .5⊥3 4 5        (Evaluates the polynomial (3×.5*2)+
7.75                  (4×.5)+5. The left argument is extended
                      to become a 3-element vector.)
```

REPRESENT: $R \leftarrow A \top B$

The represent function represents its right argument in the number system described by its left argument. For example, `2 2 2⊤5` gives `1 0 1`. The left argument contains the radices of the number system. For a vector left argument and a scalar right argument, the result is given by the following function:

```
    ∇R←A SREP B;N;□CT
[1]   N←⍴A
[2]   R←N⍴□CT←0
[3] L1:→(N=0)/0
[4]   R[N]←A[N]|B
[5]   B←B-R[N]
[6]   →(B=0)/0
[7]   B←B÷A[N]
[8]   N←N-1
[9]   →L1 ∇
```

This function is a generalization of the usual method of converting between number systems by dividing and finding remainders.

Requirements for A and B. A and B may have any shape. Each element of B is represented according to the radices in each vector along the first coordinate of A. (If A is a scalar, it is treated as a one-element vector for this operation.) The dimensions of the result are $(\rho A),\rho B$ (i.e., the same as for outer product).

Examples.

```
      10 10 10⊤273
2 7 3

      24 60 60⊤3723 (3723 seconds is 1 hour,
1 2 3                2 minutes, and 3 seconds.)

      2 2 2⊤31      (High-order information is lost.)
1 1 1

      0 2 2⊤31      (High-order information is
7 1 1                intercepted by using a zero.)

      10 10 10⊤34 281
0  2
3  8
4  1

      □←A←3 2⍴0 10 2 10 2 10
0 10
2 10
2 10

      A⊤281 323
70 80
 2  3

 0  1
 8  2

 1  1
 1  3
```

EXECUTE: *R←⍎B*

The execute function performs the APL statement in the vector or scalar *B*. A result is returned only if the expression produces a result. When the execute function is performed as the last operation on a line, any result is automatically printed unless specification or a branch was the last operation within the argument. Branching in the argument has no effect, and any statement label is ignored. If execute is applied to a character argument representing a list, the list is printed and the first list element is returned as the result of the execute function. Note that the present system does not allow expressions exceeding 150 characters to be executed. (Some statements of as few as 87 characters give a *LIMIT ERROR*.)

Examples.

```
      ⍎'1 24 48'   (Converting characters to numbers.)
1 24 48

      X←1 2 3
      +/⍎'X+X*2'
20

      P←⍎'A←⍳3'
      P
1 2 3

      P←⍎'2;3;4'
2 3 4

      P
2
```

MONADIC FORMAT: $R←⍕B$

The monadic format function returns a character array that when printed looks exactly like B (except possibly when $⎕PW$ is exceeded, in which case numbers in $⍕B$ could be split between lines). An argument of character type is returned unchanged. For a numeric argument, each column of B becomes several columns in the result (depending on $⎕PP$ and the numbers in the column), but the other dimensions of the result are the same as for the argument. Thus the rank of R is the same as the rank of B, and $⍴R$ matches $⍴B$ except that $¯1↑⍴R$ (the last dimension of R) is generally greater than $¯1↑⍴B$ (the last dimension of B). Note that the exact output format differs between APL systems and may even differ between versions of the same system. Programs should be written to be independent of such differences.

Special case. A scalar numeric argument is treated as a one-element vector and thus produces a vector result.

Examples.

```
      ⍕1 2 3
1 2 3

      ⍴⍕1 2 3
5

      ⍕3 4⍴⍳12
1  2  3  4
5  6  7  8
9 10 11 12
```

```
      ρ▼3 4ρ⍳12
 3   10

      ▼'AB'
AB
```

DYADIC FORMAT: *Z←V▼B*

The dyadic format function represents columns of *B* according to pairs of integers in the vector *V*. The first number of a pair in *V* gives the width, and the second number gives the precision to be used in representing the number. The width is the number of character positions to be used for the column, and if 0 is used, the system chooses a width so that at least one blank will separate that column from the preceding column. The result *R* has the same dimensions as *B* except that the last dimension of *R* is usually greater than the last dimension of *B*. Character arguments are not allowed. The precision has the following significance:

precision≥0 The numbers are represented in decimal format. The precision is the number of digits beyond the decimal point. If the precision is zero, no decimal point appears.

precision<0 The numbers are represented in exponential format. The number of digits shown is the absolute value of the precision, and if the number of digits is 1, no decimal point appears. Five columns are reserved for the exponent when the system chooses the width. When the width is provided the number of columns reserved at the right for the exponent is given by $5\lfloor W-D+1+1\neq D$, where *W* is the width and *D* is the number of digits.

If a number cannot be represented in the space provided, the field for that number is filled with asterisks. However, there is no requirement that spaces separate numbers in the same row.

Exception cases. If *B* is a scalar, it is treated as a one-element vector. (Hence the result is a vector, never a scalar.) If *V* is a scalar or one-element vector, it is extended to become *V*←0,*V*. (Thus the width of the columns will be chosen by the system.) Then if ρ*V* is 2 but ¯1↑ρ*B* (the last dimension of *B*) is not 1, *V* is replicated to become *V*←(2×¯1↑ρ*B*)ρ*V* so that the pair of numbers in *V* will be applied to all columns.

Examples.

```
      7  3⍕.3456  2.8  928
0.346  2.800928.000

      4⍕.3456  2.8  928
0.3456 2.8000 928.0000

      1 0⍕3 3⍴1 0
101
010
101

      10 ¯3⍕3 1⍴2.34567 4.23E18 ¯5.3E¯6
 2.35E0
 4.23E18
¯5.30E¯6

      ¯1⍕1E5 1.2E6 1.8E2
1E5 1E6 2E2
```

MATRIX INVERSE: *R*←⌹*B*

The matrix inverse function returns the inverse of a matrix *B*. The inverse is such that

(⌹*B*)+.×*B*←→*I*

where *I* is an identity matrix (i.e., a matrix with 1's along the diagonal and 0's elsewhere) having 1↑⍴*B* rows and columns. Note that this uniquely defines *R* only as long as *B* has the same number of rows and columns. However, if *B* has more rows than columns, the result *R* can be uniquely defined by *R*←→(⌹(⍉*B*)+.×*B*)+.×⍉*B*. The result is related to the result for the dyadic matrix divide function according to ⌹*B*←→*I*⌹*B*, where *I* is an identity matrix having ¯1↑⍴*B* rows and columns.

Requirements for *B*. Ignoring the exceptions below, *B* must be a matrix such that (1↑⍴*B*)≥¯1↑⍴*B* (*B* must have at least as many rows as columns) and *B* must have an inverse. Note that some matrices do not have inverses and produce a *DOMAIN ERROR* if an inverse is requested. In particular, a square matrix with two identical rows or with one row that can be produced by multiplying other rows by factors and adding them has no inverse. Actually, there is no precise distinction between matrices that have inverses and those that do not, and ⎕*CT* is used in the test. Decreasing the value of ⎕*CT* may prevent a *DOMAIN ERROR*, but the result so produced is less reliable and may be completely meaningless. The dimensions of the result are ⌽⍴*B* (i.e., ⍴⍉*B*).

Special cases. If B is a scalar, the result is the scalar $\div B$. If B is a vector, the result is $B\div+/B*2$. Except for the result rank, the scalar case is the same as if the scalar were treated as a one-by-one matrix, and the vector case is the same as would be produced by treating the vector as a one-column matrix.

Examples. See the examples at the end of the following discussion of matrix divide.

MATRIX DIVIDE: $R\leftarrow A\boxdot B$

The matrix divide function solves systems of simultaneous equations or finds least-squares regression coefficients. When the matrix B has the same number of rows and columns, R is the solution to linear equations represented by the constant vector A and the coefficient matrix B. When B has more rows than columns, the result R contains the regression coefficients for a dependent variable A and independent variables in the columns of B. Note that the result is the same as $(\boxdot B)+.\times A$.

Requirements for A and B. Ignoring the special cases below, B must be a matrix such that $(1\uparrow\rho B)\geq 1\uparrow\rho B$, and B must have an inverse (see the preceeding discussion of the matrix inverse function). Also, A must be a matrix such that $(1\uparrow\rho A)=1\uparrow\rho B$ (they must have the same number of rows). When A has more than one column, the result R has a solution column for each column of A. The result has the dimensions $(1\downarrow\rho B),1\downarrow\rho A$ (one row for each column of B and one column for each column of A). The result R satisfies $B+.\times R\leftrightarrow A$ if B is a square matrix. When B is not a square matrix, the result minimizes each element of

$$+/(A-B+.\times R)*2$$

That is, $B+.\times R$ gives predicted values for the regression cofficients R, and $A-B+.\times R$ gives the residuals; so the sum of the squared residuals is minimized.

Special cases. The arguments may also be scalars or vectors. A scalar is treated as a one-by-one matrix, and a vector is treated as a one-column matrix. After this extension, $1\uparrow\rho A$ must match $1\uparrow\rho B$. The dimensions of the result are $(1\downarrow\rho B),1\downarrow\rho A$ where A and B here are the original arguments before extension.

Example 1. To solve the system of equations:

```
5= x + 2y
4=5x + 3y
```

Use:

```
      □←M←2 2⍴1 2 5 3
1 2
5 3
```

```
      5  4  ⌹M
¯1  3    (A vector result.)

      (2 1⍴5 4)⌹M
¯1
 3       (A matrix result.)
```

The answer is x=¯1, y=3.

Example 2. Given $V1$←.8 .9 1.0 2.2 3.1, $V2$←1 2 3 1 2, and Y←4.5 6.6 9.2 8.3 7.1 find the values of $A1$ and $A2$ that most nearly satisfy $Y=(A1\times V1)+A2\times V2$ in the least squares sense.

```
      □←Q←V1,[1.5]V2
0.8 1
0.9 2
1   3
2.2 1
3.1 2

      □PP←3
      □←Z←Y⌹Q
1.37 2.56
```

The predicted values for Y are:

```
      Q+.×Z
3.66 6.35 9.04 5.58 9.37
```

and the residuals are:

```
      Y-Q+.×Z
0.845 0.252 0.159 2.72 ¯2.27
```

Example 3. Using $V1$ and $V2$ from Example 2 and $Y2$←6.5 8.6 11.2 10.3 9.1, find $A1$, $A2$, and $A3$ that most nearly satisfy $Y2=A1+(A2\times V1)+A3\times V2$. This problem is like the previous one except that we imagine $A1$ to be the coefficient of a vector of 1's. The solution is given by:

```
      □←B←1,Q
1 0.8  1
1 0.9  2
1 1    3
1 2.2  1
1 3.1  2

      Y2⌹B
5.76 0.593 1.35
```

Section 7. Composite Functions

As described in Section 3, an operator is a special function that takes functions as arguments and produces a function as a result. Except for the result of the axis operator, these resulting functions are the composite functions. A few examples will help to illustrate this. The expression +/1 2 3 ("the plus reduction of 1 2 3") is the same as 1+2+3. Similarly, -/1 2 3 is 1-2-3 or 2 (remember that it is performed from right to left). The function symbol to the left of the slash indicates the particular dyadic scalar function to be used. The forms for composite functions are d/*B* (reduction), d*B* (scan), *A*∘.d*B* (outer product), and *A*d.D*B* (inner product), where d and D represent symbols for any dyadic scalar functions.

REDUCTION: *R*←d/[*K*]*B*

Reduction applies a dyadic scalar function repeatedly between elements in vectors along the *K*th coordinate of *B*. For a vector *B*, the reduction is of the form

B[1]d*B*[2]d ... d*B*[*N*]

For higher order arrays the same sort of operation is performed for each vector along the *K*th coordinate. When the axis operator is omitted the operation is performed along the last coordinate. The alternate symbol ⌿ can be used to indicate the operation should be performed along the first coordinate.

Requirements for *B*. Elements of *B* must be in the domain of the scalar function used. Thus, character arguments are allowed only for the functions = and ≠. Except for the special cases below, the result has a rank that is one less than the rank of *B* and the dimensions of the result are (*K*≠⍳⍴⍴*B*)/⍴*B* (the same as the dimensions of *B* except that the *K*th dimension of *B* is missing).

Special cases. A scalar is treated as if it were a one-element vector, and the result is then a scalar. If the length of *B* along the *K*th coordinate is 1, the result is the same as the argument except that one dimension is removed. No operation is actually performed in this case, so no check is made to see whether the values are in the domain of the function, except that arguments of character type are still illegal for functions other than = and ≠. When *B* is empty but the result is not empty, the result contains the identity element for the function if one exists. The following table shows the identity elements used. Note that in some cases the identity elements are identities in a rather loose sense. Some are right identities only, some are left identities only, some are both, and some are identities only for logical arguments. Functions for which there is no identity in the table produce *DOMAIN* errors when applied along a coordinate of length 0.

Function	Identity	Function	Identity
+	0	*	1
-	0	∧	1
×	1	∨	0
÷	1	!	1
⌈	¯1.26*E*322	>	0
⌊	1.26*E*322	≥	1
=	1	<	0
≠	0	≤	1
		|	0

Examples.

```
      ⌈/3 1 9 15
15                    (Largest element.)

      ⌊/3 1 9 15
1                     (Smallest element.)

      ×/1 2 3 4 5
120                   (Product.)

      +/1 2 3 4 5
15                    (Sum.)

      -/1 2 3 4 5     (Alternating sum; same as
3                      1+(-2)+3+(-4)+5.)

      ÷/1 2 3 4 5     (Alternating product; same
1.875                 as (1×3×5)÷2×4.)

      □←P←3 4⍴⍳12
1  2  3  4
5  6  7  8
9 10 11 12
```

```
      ⌈/P          (Largest element in each row.)
4  8 12

      ⌈⌿P          (Largest element in each column.)
9 10 11 12

      +/3          (A scalar is treated as a vector.)
3

      ∧/5
5                  (No domain check for one element.)

      +/⍳0
0                  (An identity if the length is zero.)

      +/3 0⍴0
0 0 0              (An identity for each of the 3 rows.)

      ∧/A∈B        (Gives 1 if all elements of the vector A
                    occur in B.)

      ∨/A∈B        (Gives 1 if any elements of the vector
                    A occur in B.)
```

SCAN: $R \leftarrow d\backslash[K]B$

Scan performs a series of reductions. For example, +\1 2 3 4 5 returns 1 3 6 10 15; that is, the Ith element is $+/I\uparrow B$. For arrays other than vectors, the result has the same shape as the argument, and the elements along the Kth coordinate are produced by performing a reduction over the first I elements. Arguments of character type are not allowed. If the axis operator is absent, the last coordinate is assumed. The alternate symbol ⍀ can be used to indicate the operation is the be performed along the first coordinate.

```
      ∨\0 0 1 0 0 1 0
0 0 1 1 1 1 1

      ∧\1 1 0 1 0 1
1 1 0 0 0 0

      ×\1 2 3 4 5 6
1  2  6  24  120  720

      □←P←3 4⍴⍳12
1  2  3  4
5  6  7  8
9 10 11 12
```

```
      +\P
 1  3  6 10
 5 11 18 26
 9 19 30 42

      +⍀P          (Same as  +\[1]P.)
 1  2  3  4
 6  8 10 12
15 18 21 24
```

OUTER PRODUCT: $R\leftarrow A\circ.dB$

Outer product applies a scalar dyadic function using all elements of A as left arguments and all elements of B as right arguments. The rank of the result is $(\rho\rho A)+\rho\rho B$ and the dimensions of the result are $(\rho A),\rho B$. Each result element has as its first $\rho\rho A$ indices the indices of the element used from A and has as its last $\rho\rho B$ indices the indices of the element used from B.

Examples.

```
      1 2 3∘.×4 5 6 7
 4  5  6  7
 8 10 12 14        (Each element of the left argument is
12 15 18 21         multiplied by each element of the right.)

      1 2 3∘.=3 1 3
0 1 0
0 0 0
1 0 1

      +/1 2 3∘.=3 1 3
1 0 2             (The number of 1's, 2's and 3's
                   in the right argument.)
```

INNER PRODUCT: $R\leftarrow Ad.DB$

Inner product applies the scalar function D between each vector along the last coordinate of A and each vector along the first coordinate of B, then performs a reduction using d to that result. The usual matrix product is $A+.\times B$.

Requirements for A and B. Ignoring the special cases below, the last dimension of A must match the first dimension of B. The dimensions of the result are $(\bar{}1\downarrow\rho A),1\downarrow\rho B$ (all dimensions of A except the last and all dimensions of B except the first).

Special cases. If A or B is a scalar it is treated as a one-element vector. Then if the last dimension of A does not match the first dimension of B but one of the two dimensions is 1, that dimension is extended to match the other (thus allowing the array having the 1 as a dimension to be used repeatedly).

Examples. The following table shows examples for arguments of various ranks.

$\rho\rho A$	$\rho\rho B$	$\rho\rho R$	Result
2	2	2	$R[I;J]=d/A[I;]DB[;J]$
2	1	1	$R[I]=d/A[I;]DB$
1	2	1	$R[I]=d/ADB[;I]$

The following examples illustrate useful inner products:

```
      □←A←2 3⍴1 0
1 0 1
0 1 0
      □←B←3 3⍴⍳9
1 2 3
4 5 6
7 8 9
      A+.×B          (Matrix Product.)
8 10 12
4  5  6

      'ABCD'+.='XZCD'(Counts matches in corresponding
2                     positions.)

      □←TABLE←3 4⍴'FOURFIVESIX '
FOUR
FIVE
SIX

      TABLE∧.='FIVE'
0 1 0               (Gives 1 for a row that matches
                     'FIVE'.)
```

Section 8. System Functions and Variables

This section discusses system functions and variables other than ⎕, ⍞, ⎕*FD*, and ⎕*SY*, which are described elsewhere. System functions and variables allow communication with the APL system, and, to some extent, with the operating system under the control of which the APL system runs. In most respects system functions and variables behave as other APL functions and variables except that: their names are distinguished by beginning with the symbol ⎕ or ⍞, they control the APL environment in ways that other functions and variables cannot, and the values of system variables can change between settings. For example, ⎕*AI*, which is a vector of accounting information, may be set by the user to any desired value, but the next time he requests its value, it will correctly reflect current accounting information--that is, the system resets the value of ⎕*AI* before it is read. Similarly, ⎕*AI* can be erased by the user, but the system gives it a value whenever its value is requested.

The system variables that affect operation of the APL system have restricted shapes and domains. For example, ⎕*IO*, the origin for indexing, must have a value of 1 or 0. Any attempt to set ⎕*IO* to an improper value will result in a *RANK ERROR* or a *DOMAIN ERROR*. However, the user can erase ⎕*IO* or declare ⎕*IO* to be local to a function and then fail to assign it a value. When a system variable is undefined and its value is required for an operation, an *IMPLICIT ERROR* results. For example:

```
      ∇Z←IOTA B;⎕IO  (⎕IO is a local variable.)
[1]   Z←⍳B ∇

      IOTA 3
01: IMPLICIT ERROR
IOTA[1] Z←⍳B
          /
```

Table 8-1. Summary of Section 8.

Output Control
⎕PP←integer (1 to 15) Printing precision--maximum number of significant digits used for numeric output. *⎕PW←integer (30 to 131071)* Maximum printing width used for output. *⎕PL←pagesize,linecount (0 to 131071)* Print lines. Print lines to be used before a halt to allow the terminal operator to intervene, and count of lines used. If *⎕PL*[1] is 0, output will be uninterrupted. *⎕HT←integers* Horizontal tabs. Indicates to the APL system where tab stops have been set on the terminal.
Indicators affecting Primitive Functions
⎕CT←number (0 to .01) Comparison tolerance used for relational functions, membership, index-of, integer tests, and domain tests. *⎕IO←0 or 1* Index origin. Determines base for counting. *⎕RL←integer (1 to 281474976710655)* Random link used by random number functions.
Function Definition
⎕ENV←0 or 1 Environment control. Affects *⎕CR*, *⎕FX*, *⎕EX*, *⎕NC*, *⎕NL*, *⎕STOP*, *⎕TRACE*, *⎕LOCK*, *⎕LTIME*, *⎕NAMES*, and *⎕COPY*. If *⎕ENV* is 0, the global environment is used, and if *⎕ENV* is 1, the current environment is used. *matrix←⎕CR 'name'* Canonical representation of a function in the form of a matrix. *Z←⎕FX matrix* Fixes the function represented by the character matrix argument. The result returned is a vector containing the name of the function, or, if the operation failed, a numeric scalar line number for the erroneous statement. *vector←⎕EX 'names'* Expunges (erases) objects named by the right argument. The result contains 1's for names that are now available, 0's for others.

Table 8-1. Summary of Section 8, Continued.

vector←⎕*NC* '*names*' Returns the name class for each name--0 for available, 1 for locked variable (label or group), 2 for unlocked variable, 3 for function, or 4 for distinguished name. *matrix*←⎕*NL V* *matrix*←'*letters*' ⎕*NL V* The namelist functions return matrices of names in use. Which names are returned depends on class numbers in *V*--locked variables (labels or groups) if $1 \in V$, unlocked variables if $2 \in V$, functions if $3 \in V$, and defined distinguished names if $4 \in V$. The left argument of the dyadic form should contain letters to further restrict names to those beginning with those letters. *vector*←⎕*LOCK* '*names*' Locks functions and variables named by the right argument. The result is a vector containing 1's for success, 0's for failure.
Stop, Trace, and Timing Control
V ⎕*STOP* '*name*' *V* ⎕*TRACE* '*name*' *V* ⎕*LTIME* '*name*' Sets stop, trace, or timing controls for lines specified by *V* and clears controls for other lines. *Z*←⎕*STOP* '*name*' *Z*←⎕*TRACE* '*name*' *Z*←⎕*LTIME* '*name*' Returns line numbers for which stop, trace, or line timing controls are set. ⎕*STOP* and ⎕*TRACE* return vector results, while ⎕*LTIME* returns a matrix with line numbers in column 1 and corresponding times in column 2.
Program Library Functions
⎕*WSID*←'*name*' ⎕*WSID* contains the workspace identification of the active workspace. This name is used when no name is given for ⎕*SAVE*.

Table 8-1. Summary of Section 8, Continued.

Z←⎕*SAVE* ' *wsname* [:*passwd*][/*options*]'
Saves a copy of the acti3e workspace under the name specified. ⎕*SAVE*'' (no name given) uses the name in ⎕*WSID*.

A ⎕*SAVE* '*wsname* [:*passwd*][/*options*]'
Same as above except that *A* controls the state indicator of the active and stored workspaces. If *A* is 0 or 1 the state indicator is cleared or backed up to the last suspension, respectively.

⎕*LX*←'*expression*'
The latent expression is executed immediately after the workspace containing it is loaded.

⎕*LOAD* '[*account] *wsname* [:*passwd*]'
Activates a copy of a stored workspace and then executes the latent expression if one is defined.

matrix←*V* ⎕*NAMES* '[*account] *wsname* [:*passwd*]'
Lists names used in a stored workspace. The result is a matrix of names of objects in the name classes specified by elements of *V*--locked variables (labels or groups) if $1 \in V$, unlocked variables if $2 \in V$, functions if $3 \in V$, and distinguished names if $4 \in V$.

matrix←⎕*NAMES* '[*account] *wsname* [:*passwd*]'
Returns a matrix of all names of classes 1, 2, and 3 in the workspace.

matrix←'*names*' ⎕*COPY* '[*account] *wsname* [:*passwd*]'
Copies specified objects into the active workspace from a stored workspace.

matrix←⎕*COPY* '[*account] *wsname* [:*passwd*]'
Copies all objects of classes 1, 2, and 3 from the workspace.

⎕*DROP* '[*account] *wsname* [:*passwd*]'
Removes the stored workspace or file named by the right argument from the indicated library.

Z←⎕*LIB* '[*account] [*name*]'
Returns a matrix containing names, types, and sizes of files in a library. If an account number is given, information is given only for the files that are public or semiprivate or for which the user has access permission. If a name is given, detailed information about that one file is returned.

Table 8-1. Summary of Section 8, Continued.

Error Processing
⎕TRAP integer Specifies that errors are to be intercepted by a forced branch to the specified line of the currently executing function. *Z←⎕ERR* *⎕ERR* is a 3-row matrix of the last error message, the line having the error, and a pointer to the position of the error in the line. *matrix←⎕SIV vector* The result is a character matrix containing the rows of the state indicator with variables display specified by the right argument. *⎕SIV⍳⎕LC* gives the entire display (in either origin). *V←⎕LC* *⎕LC* is a vector of all line numbers appearing on the state indicator.
Miscellaneous System Communication
V←⎕AI *⎕AI* is a vector of accounting information. *⎕AI*[1 2 3 4 5] gives: an encoding of the user's account number, accumulated central processor time, accumulated connect time, accumulated keying time, and SRU's used. *V←⎕AV* Atomic vector of all 256 APL characters. *V←⎕TS* Time stamp: current year, month, day, hour, minute, second, and millisecond. *V←⎕TT* Terminal type. *⎕WA←V* Working area: *⎕WA*[1] is the part of the maximum field length available for use, *⎕WA*[2] is the current field length, *⎕WA*[3] and *⎕WA*[4] are the minimum and maximum field lengths the user wishes APL to use. *Z←⎕TM 'command'* Terminal mode: commands are *SYSTEM*, *OFF* and *ABORT*, to return to operating system command processor, sign off, or abort batch job.

Table 8-1. Summary of Section 8, Continued.

S←⎕*DL seconds* Causes execution to delay for the specified number of seconds.
Format System Function
Z←'*phrase,phrase, ...* ' ⎕*FRMT B* *Z*←'*phrase,phrase, ...* ' ⎕*FRMT* (*B1;B2; ...*) Formats right argument according to left argument. A *phrase* is of the form 3*qI*4, 2*qF*9.2, 4*E*15.7, 4*A*1, ⍞*text*⍞, or 5*X*. The qualifier *q* may be a combination of *C*, *T*, *Z*, or *L* (for commas, to change trailing zeros to blanks, use leading zeros, or to left justify); *R*⍞*text*⍞ (to pre-fill with *text*); *M*⍞*text*⍞ or *N*⍞*text*⍞ (to place *text* to left or right if negative); *P*⍞*text*⍞ or *Q*⍞*text*⍞ (to place *text* to left or right if positive), *N*, *B*, or *P* (to replace with blanks if negative, zero, or positive); or *N*⍞*text*⍞, *B*⍞*text*⍞, or *P*⍞*text*⍞ (to replace with *text* if negative, zero, or positive).
Number Conversion
Z←⎕*EXTRACT*'*characters*' Scans argument for numbers. *Z*[1] tells the number of characters scanned, and 1↓*Z* gives a vector of any valid numbers encountered.

However, three system variables are so important that when they are undefined the system uses default values. Thus, when ⎕*PW* is undefined the system uses 30 as the printing width. When ⎕*PP* is undefined, normal output uses a value of 1. When ⎕*CT* is undefined, the system uses zero as the comparison tolerance for domain tests, although numerical comparisons still give implicit errors. For example,

```
      ⎕EX'⎕CT'
1
      3=3
01: IMPLICIT ERROR  (Because ⎕CT is undefined for comparison.)
      3=3
      /
      ⍳3
1 2 3
      ⍳3+1E¯12
03: DOMAIN ERROR  (Because ⎕CT is zero for domain tests.)
      ⍳3+1E¯12
      /
```

Certain system variables are not stored in the workspace. These session variables remain in effect if another workspace is loaded and always have their normal values when an APL session begins. The session variables are ⎕*HT*, ⎕*WA*, ⎕*PL*, ⎕*TT*, ⎕*TS*, and ⎕*AI*.

Note that many system variables are concerned with internal intricacies of the APL system or the host operating system. Consequently, they can be expected to differ from one system to another. For some programs it may be worthwhile to access them through user-defined functions to reduce the number of locations requiring changes if the program is later moved to another system.

NAME LISTS

Some system functions require arguments consisting of lists of names. In all cases such name lists can be either a vector of names separated by spaces, or a matrix of names with one name in each row. In either form extra spaces are allowed before or after names. When a system function returns a list of names as a result, the list is always in the form of a matrix because the matrix form is usually more convenient for manipulation by the program.

WORKSPACES

An APL workspace comprises variables, user-defined functions, the state indicator, and system variables that are currently defined. A clear workspace comprises the following:

an empty state indicator
⎕*PP*←10 (printing precision of 10 digits)
⎕*PW*←120 (up to 120 characters are printed per line)
⎕*CT*←5*E*¯11 (comparison tolerance is 5*E*¯11)
⎕*IO*←1 (index origin is 1)
⎕*RL*←16807 (random link is 16807)
⎕*ENV*←1 (local environment)
⎕*ERR*←3 0⍴''

As functions and variables are defined, they become part of the active workspace. A copy of an active workspace can be saved. To use it at a later time, a copy of the saved workspace can be activated (that is, made active).

A stored workspace is a special kind of "file." Under an account number (or user number) can be stored as many files as are allowed by restrictions imposed on the account number. The collection of files is known as a library.

APL workspaces and data files are ordinarily *private* files, which means that other users cannot use them. A user may optionally save a workspace as a *semiprivate* file or *public* file by use of commands of the form)*SAVE 'name/S'* or)*SAVE 'name/PU'*. This allows other users to access the workspace but does not allow them to alter it. Other users can be given permission to access a *private* file by use of the PERMIT control card (see Section 13). This gives selected user numbers permission to access the particular file. Further details about these file categories can be found in Section 10 and Section 13.

Passwords can be given to workspaces for additional security. When a workspace is given a password, other users must provide the password in order to access the workspace. However, the owner of the workspace need not provide the password in order to use it.

The first time a workspace is saved it can be given a password or a category (i.e., *private*, *semiprivate*, or *public*). Thereafter, the file password and category remain unchanged for subsequent save commands that replace the stored workspace. (Thus, the password and category options should not be provided for subsequent save commands.) To change the password or category you must load the workspace, drop the stored one, and then resave it with the new options. Alternatively, you can use the CHANGE control card (see Section 13).

Workspaces can optionally be saved in *direct access* form (ordinarily they are saved in *indirect access* form). This option is chosen by using a command of the form)*SAVE 'name/DA'* the first time the stored file is established. *Direct access* workspaces are faster to load, save, or copy, but require more disk space. The *direct access* option is appropriate for unusually large workspaces that are loaded or saved very often. A workspace can be changed to *direct access* form by loading it, dropping it, then resaving it using the *DA* option.

Workspace names and passwords must be composed of 1 to 7 letters and digits. Embedded spaces are not allowed.

NOTATION

Throughout this section, brackets are used to surround optional portions of expressions. The brackets themselves should not be used. For example,

```
□LOAD '[*account] wsname [:passwd]'
```

means that the account number and password are optional. Any of the following commands are of the correct form:

```
□LOAD 'ALGEBRA'
□LOAD '*A123456 ALGEBRA:SESAME'
□LOAD 'ALGEBRA:SESAME'
□LOAD '*A123456 ALGEBRA'
```

SYSTEM VARIABLES FOR OUTPUT CONTROL

Printing precision. *□PP←integer (1 to 15)*
The value of *□PP* determines the maximum number of significant digits to be used for numeric output. The result is rounded to *□PP* digits; hence if *□PP* is 3, 0.34567 would be printed as 0.346. See Appendix B for further details of numeric output format.

Printing width. *□PW←integer (30 to 131071)*
The value of *□PW* determines the line width used for output. When a line of output requires more character positions than *□PW*, the remaining characters are indented and continued on successive lines. Output of numbers will not cause individual numbers to be split between two lines, but output of character data representing numbers may cause numbers to be split between lines.

Print lines. *□PL←pagesize, linecount (0 to 131071)*
□PL is primarily intended to facilitate the use of CRT terminals having a screen smaller than the total amount of output generated. Appropriate setting of *□PL* causes output to pause when the screen has been filled to allow the screen to be examined or cleared (if required) before more output is sent. The first element of *□PL* should be set to the number of lines that will be used for actual output. The second element of *□PL* is a count of the number of lines actually used for input and output. When each output line or input line has been completed, *□PL*[2] is incremented by 1. If *□PL*[1]=*□PL*[2], the system prints *?* on the next line and suspends further output until RETURN is pressed. (Any other input is treated as if RETURN has been pressed.) The program requesting input can be halted by use of an interrupt (see Appendix C). When RETURN is pressed, *□PL*[2] is reset to 0, and further output is sent. The value of *□PL*[2] can be reset to compensate for screen repositioning caused by graph mode output. The elements of *□PL* are restricted to nonnegative integer values. If an attempt is made to set *□PL*[1] to 1, it

actually is set to 0. If the last line on the screen is used for input, the ? is suppressed and normal input can be entered on that line. (The input request gives a pause to allow the screen to be read.) Note that for some terminal types the ? prints as \.

⎕*PL* has a different meaning when APL output is sent to a file rather than to a terminal. Specifically, if APL is not being used from a terminal or is being used from a terminal but the output file name is not OUTPUT, and if the *B* (for leading blanks) output option is in effect (see Appendix D), a page eject carriage control character is sent at the beginning of the next output line whenever the page size has been exhausted.

Horizontal tabs. ⎕*HT*←*integers*
The variable ⎕*HT* can be set to indicate to the APL system that the terminal has tab stops set at the indicated locations. APL will subsequently send tab characters rather than spaces whenever the tab character will improve output speed. The first terminal column is numbered as column zero. Tab positions greater than 255 are ignored and positions beyond ⎕*PW* are inconsequential. If there is a discrepancy between the actual tab settings on the terminal and the values in ⎕*HT*, the output will be printed incorrectly. Also, some terminals cannot keep up with the output when the tabs are too far apart. To use tab stops set every *N* spaces, you can set ⎕*HT* using an expression like ⎕*HT*←*N*×⍳100. To revert to normal output without use of tabs you can set ⎕*HT* using ⎕*HT*←⍳0.

VARIABLES AFFECTING PRIMITIVE FUNCTIONS

Comparison tolerance. ⎕*CT*←*number (0 to .01)*
The comparison tolerance is used when comparing numeric values and when testing whether values are sufficiently close to integers:

1. Two numbers *A* and *B* are considered equal only if

   (⌈*A*-*B*)≤|⎕*CT*×*B*

2. A number *B* is considered to be in the integer domain if

   (⌈(*NINT B*)-*B*)≤⎕*CT*+⌈⎕*CT*×*NINT B*

   where *NINT B* is the nearest integer to *B*, defined by:

```
     ∇Z←NINT B
[1]  Z←(×B)×⌊.5+|B∇
```

   The value actually used for the operation is *NINT B*. If ⎕*CT* is undefined, zero is used as ⎕*CT*.

Random link. ⎕*RL*←*integer (1 to* 281474976710655*)*
⎕*RL* determines the next random number to be produced by roll or deal. Each time a random number is requested, the value of ⎕*RL* changes. A series of random numbers can be recreated by setting ⎕*RL* to the same initial value and repeating the same requests. Because the value of ⎕*RL* is saved with the workspace, it may be desirable to reset it after the workspace is loaded to a value based on the current time of day so that the random numbers produced will not be the same as for the last session; for example, ⎕*RL*←+/⎕*TS*.

Index origin. ⎕*IO*←0 *or* 1
The index origin determines the origin for counting coordinates or elements along coordinates. In 0-origin the elements of a vector would be numbered 0, 1, 2, etc. All indexing should use

values that are 1 less in 0-origin than in 1-origin. In addition, the following functions produce results that are 1 less in 0-origin than in 1-origin: *A⍳B*, *⍳B*, *⍋B*, *⍒B*, *A?B*, and *?B*. In addition, the left argument for dyadic transpose should be 1 less for 0-origin, and all axis operators require values that are 1 less. That is, *K* should be 1 less in expressions like *A/[K]B* and *⌽[K]B*.

FUNCTION DEFINITION

Environment. *□ENV←0 or 1*

□ENV controls whether the functions *□CR*, *□FX*, *□EX*, *□NC*, *□NL*, *□LTIME*, *□NAMES*, *□COPY*, *□STOP*, *□LOCK*, and *□TRACE* refer to the global environment or to the current environment. When *□ENV* is 0, the global environment is used, and when *□ENV* is 1, the current environment is used. The normal value of *□ENV* is 1, so the system functions listed above may refer to local variables and functions. However, when function definition mode is entered or when a system command is performed, only the global functions and variables are used. When the state indicator is empty, the current environment and the global environment are the same and *□ENV* has no effect.

Canonical representation. *matrix←□CR 'NAME'*

Canonical representation returns a character matrix representation of a function. The right argument contains a character vector or scalar containing the name of the function to be returned. The result will have one row for each line of the function, including the function header. Lines will be indented one space unless they have labels. If the argument does not name an object in the environment specified by *□ENV*, a *NAME NOT FOUND* error is given. If the function named by the argument is a locked function or is a variable, the result will have 0 0 as its shape.

Fix. *Z←□FX matrix*

□FX establishes the function represented by the character matrix argument. If the attempt to establish the function is successful, *Z* will be a vector containing the name of the function. Replacement of previously existing functions is allowed and may result in *SI DAMAGE* if the function is halted. The *SI DAMAGE* error is processed as a normal error, except that if the state indicator entry for the currently executing function was damaged, error trapping is not allowed to take place. In this case the error is considered to be located at the last line entered in immediate execution mode. *□FX* cannot be used to replace objects other than functions. An attempt to establish a function may also fail as a result of an incorrectly formed function header or duplicate use of statement labels or local variables. If the attempt fails, *Z* will contain a scalar row index of the line that was improper. Functions created by *□FX* can be declared local to other functions.

Expunge. *vector←⎕EX 'names'*
⎕EX expunges (erases) functions and variables named by the argument. The result is a logic vector containing 1's in positions corresponding to names in the argument that are now free, and 0's in positions corresponding to names that remain unavailable for new uses. Erasure of a function that is on the state indicator does not take effect until the function is no longer on the state indicator. Thus a function can erase itself and not actually be erased until it exits. The unfinished execution can complete, but the name is immediately available for new uses.

Name class. *vector←⎕NC 'names'*
⎕NC returns information about use of the names in the right argument. The result contains 0, 1, 2, 3, or 4 according to whether the name is available (not in use), a locked variable (label or group), unlocked variable, a function, or a defined distinguished name (i.e., beginning with the symbol ⎕), respectively. Incorrectly formed names in the argument cause a *DOMAIN ERROR*.

Name list. *matrix←⎕NL V* or *matrix←'letters' ⎕NL V*
The name list functions return lists of names in use. The right argument is a numeric vector such that *∧/V∈1 2 3 4*. *V* indicates the classes of names for which information is desired--1 for locked variables (labels or groups), 2 for unlocked variables, 3 for functions, and 4 for distinguished names (i.e., those beginning with the symbol ⎕). The result is a matrix of the names. The left argument of the dyadic form may contain any number of letters, and names appear in the result only if they begin with those letters.

Lock. *vector←⎕LOCK 'names'*
The variables and functions specified by the right argument are locked. A locked function cannot be displayed, and a locked variable cannot be reset using specification. (However, a locked variable can be reset by erasing it and then using specification.) Locking a variable is a very useful way to find where the variable is reset. When the variable has been locked, the next assignment to it will cause an error halt. Label variables and groups are automatically locked to prevent them from having improper values. The result returned by *⎕LOCK* contains 1's in positions corresponding to names that are now locked and contains 0's for other names.

STOP, TRACE, AND TIMING CONTROL

The functions *⎕STOP*, *⎕TRACE*, and *⎕LTIME* are closely related. In each case the right argument is a character vector or scalar that names a function, and the left argument for the dyadic form must contain nonnegative line numbers for which the control is to be set. Setting controls for any lines clears all controls of the same type for the other lines of the function. Elements of

the left argument not in the range of line numbers are ignored. In all cases, an empty vector of line numbers can be used to clear the controls. An empty character vector is allowed as a left argument for notational convenience (e.g., '' ⎕*STOP* '*PLOT*'). The monadic forms of the functions return information about controls that are currently set.

Stop control. *V* ⎕*STOP* '*name*' and *vector*←⎕*STOP* '*name*'
When the stop control is set for a particular line, execution of the function suspends before execution of the line begins, and the system prints *STOP SET*, the name of the function, and the line number. To continue execution where it stopped, issue a branch to the line number just printed. Stop control at line 0 of a function causes suspension just prior to exit from the function. The monadic form returns a vector of line numbers for which stop controls are currently set.

Trace control. *V* ⎕*TRACE* '*name*' and *vector*←⎕*TRACE* '*name*'
Setting trace control for a line causes the function name and line number to be printed each time after the line has been executed, and if the result of the line was used for a branch or assignment, the result is printed even though it ordinarily would not be. Setting trace contol for line 0 causes tracing of the exit from the function and causes printing of the explicit result of the function (if it has one). The monadic form returns a vector of line numbers for which trace controls are set.

Line timing control. *V* ⎕*LTIME* '*name*' and *matrix*←⎕*LTIME* '*name*'
Setting the line timing control for a line causes the central processor time for that line to be accumulated. The time for a line is accumulated until line timing controls for the function are reset, at which time all accumulated times are set to zero. An attempt to set the line timing control for line 0 of a function causes a *DOMAIN ERROR*. The result returned by the monadic form is a 2-column matrix--the first column contains the line numbers for which the line timing control is set, and the second column contains the total times for the lines. Because the time clock has a resolution of one millisecond, each parcel of time used by the line is measured with limited accuracy, and lines consuming very little time or lines consuming time in small parcels can be expected to show relatively large inaccuracy in accumulated times. Note that the times accumulated for a recursive function can count the time more than once.

PROGRAM LIBRARIES

Workspace identification. ⎕*WSID*←'*name*'
The variable ⎕*WSID* contains the name of the active workspace. The name of the active workspace is used as the name for storing the workspace if no name is specified when ⎕*SAVE* or)*SAVE* is used. The name must begin with a letter, which may be followed

by additional letters or numbers. No spaces are allowed within the name, but spaces may precede or follow the name. The name must not exceed seven characters.

Save. *vector*←□*SAVE* ' *wsname* [:*passwd*][/*options*]'
□*SAVE* saves a copy of the active workspace under the specified name and attaches to the saved workspace the password if one is used. If a password is used, it must be separated from the name by a colon. The name itself may be omitted, and in this case the value of □*WSID* is used as the name. When □*SAVE* is executed from a function, the state indicator of the saved workspace will show suspension where □*SAVE* was executed. The *options* may include *S*, *P*, or *PU* (for *semiprivate*, *private*, or *public* category) or may include *DA* or *IA* for direct access or indirect access. The list of options may include any desired number of options, separated by spaces, as long as the options do not include contradictory choices. The options and password may be specified only when the saved workspace is first established. If no options are specified, the workspace is saved as an indirect access private file if the saved workspace is being created; otherwise it is saved in the same form as before.

The result returned is a vector of the workspace name and the current date and time. However, when □*SAVE* is used in immediate execution mode, the name, date, and time are printed rather than being returned as a result.

Dyadic save. *A* □*SAVE* ' *wsname* [:*passwd*][/*options*]'
The dyadic save function is like the monadic form except that it permits control over the state indicator in both the active and the saved workspace. The argument *A* may be a numeric scalar or vector. If *A* is 0, a clear state indicator results, and if *A* is 1, the state indicator is backed up to the point of the most recent suspension (or cleared if there have been no previous suspensions). Note that a function calling the dyadic □*SAVE* function always ceases to execute because of the change in the state indicator, unless an error prevented completion of the operation. Dyadic save prints the workspace name and the current date and time.

Latent expression. □*LX*←'*expression*'
The latent expression in a workspace is executed immediately when the workspace containing it is loaded. When a workspace has no latent expression, the keyboard unlocks for the user to specify the first operation to be performed. A successful load operation ordinarily causes the time and date when the workspace was saved to be printed, but when the workspace contains a latent expression this message is absent.

Load. □*LOAD* '[**account*] *wsname* [:*passwd*]'
The function □*LOAD* activates a copy of a stored workspace. The right argument must contain the name of the workspace to be loaded, the password for the workspace (if it requires one), and the account number under which the workspace is stored (if

different from the user's own). A successful load results in execution of the latent expression (□*LX*) if the workspace being loaded has one. If the workspace has no latent expression, the time and date when the workspace was saved are printed. The special case □*LOAD*'*APL0 CLEARWS' is equivalent to the system command)*CLEAR*, which erases all indirect access files and unties all direct access files that were tied during the APL session.

Name list for stored workspaces. *matrix*←*V* □*NAMES* '[**account*] *wsname* [:*passwd*]'
The □*NAMES* function returns a matrix list of the names used in a stored workspace. The list returned is controlled by □*ENV* in the active workspace. The right argument is the same as the right argument for □*LOAD*. The vector *V* may contain the integers 1, 2, 3, or 4 to specify what classes of names should be returned--locked variables (labels or groups) if $1 \in V$, unlocked variables if $2 \in V$, functions if $3 \in V$, and distinguished names if $4 \in V$.

Monadic name list. *matrix*←□*NAMES*'[**account*] *wsname* [:*passwd*]'
Returns a matrix of names of all objects in the workspace. Same as dyadic form with 1 2 3 as a left argument.

Copy. *matrix*←'*names*' □*COPY* '[**account*] *wsname* [:*passwd*]'
The function □*COPY* copies functions and variables from a stored workspace to the active workspace. The account number, workspace name, and password are the same as described for □*LOAD*. The list of names in the left argument specifies objects to be copied. However, if copying the object would cause replacement of objects already in the active workspace, the copying process is inhibited. If □*ENV* is zero, copying will be from the global environment of the stored workspace to the global environment of the active workspace, and if □*ENV* is 1, the current environments will be used. The result from □*COPY* is a matrix of names of objects not copied because they were not found, because *WS FULL* occurred, or because they already were in use in the active workspace.

Monadic copy. *matrix*←□*COPY* '[**account*] *wsname* [:*passwd*]'
Like dyadic copy except that all objects of classes 1, 2, and 3 (see □*NC*) are copied.

Drop. □*DROP* '[**account*] *wsname* [:*passwd*]'
The function □*DROP* removes a stored workspace (or other file) from the user's library. A password must be specified if an account number is specified and differs from the one used to sign on to the system and if the file has a password.

Library list. *list*←□*LIB* '[**account*] [*name*] '
The function □*LIB* returns information about files stored under the specified account number (or the user's own account number if no account number is specified). When no file name is included, the list is a matrix such that each row has the following fields:

File name: 7 characters
File type: 2 characters
File size (in words): 7 characters

One space separates the file name and type.

When a file name is given, detailed information about that particular file is returned. The format when a name is provided is illustrated below:

```
      ⎕LIB'*APL1 FILESYS'
FILESYS WS   1075
IA S   RD   11478
75/05/12 11:46:58      (When created.)
75/05/30 13:03:30      (Last change.)
75/07/31 12:30:59      (Last access.)
```

The first row gives the name, type of file (*WS* for workspace, *F* for APL file, blank for all others), and the size in words. The second row indicates the file is *indirect access* (the other possibility would be *DA* for *direct access*), the file category (*S* for *semiprivate*, *P* for *private*, and *PU* for *public*), the mode of access permitted for other users (*RD* for read, *WR* for write, *RM* for read-modify, *MD* for modify, *AP* for append, *RA* for read-append), and the number of accesses that have occurred.

ERROR PROCESSING

Some system functions respond to certain error conditions by returning a result to indicate the error. However, APL handles most errors by suspending execution at the point of the error, printing a message, and unlocking the keyboard for a new command to be entered. Note that a keyboard interrupt (see Appendix C) is treated as an error, as is typing ⍁ (*O*, BACKSPACE, *U*, BACKSPACE, *T*). However, halts due to stop controls are not errors. Special exceptions arise when the error is in an argument to the execute function, in a quad input entry, in a locked function, or when ⎕*TRAP* has been used to intercept errors.

Errors in an argument to the execute function normally cause two error messages to be printed. The first shows the execute argument, and the second shows the error at the line where execute was called (more precisely, the most recent pendent line other than lines of locked functions or arguments to execute).

Errors in lines entered for quad input cause the request for input to be repeated. If the error was encountered in a function called by the input line, the request for input is not repeated and normal error processing ensues.

For security reasons, lines of a locked function are not shown in error messages. Any error in a line of a locked function is treated as if it were situated in the line where the

locked function was called (more precisely, the most recent pendent line other than lines of locked functions or arguments to execute).

The function *□TRAP* can be used to designate a line of the currently executing function to intercept errors. Once this has been done, error trapping is in effect and an error in any line of the function causes a forced branch to the trap line. The error trap is in effect for functions called by that function or for functions that are in turn called by those it calls, etc.

The scope of error trapping is analogous to the scope of local variables. A function with a trap line remains in control of errors unless a function called by it sets its own trap line. The newer trap line takes precedence over the old one until the called function completes execution or clears its trap. The trap also takes precedence over the normal processing of errors in quad input lines.

When a workspace is loaded, an interrupt may be acted upon as an error before the latent expression has been executed and the error trap has been enabled. To prevent this situation, a function with a trap can be halted using a stop control before the workspace is saved. The latent expression can then deliberately cause an error in order to invoke the trap line. (Warning: If a suspended function with a trap set is edited, any error that occurs may not trap to the expected line and the value of *□ERR* may be erroneous.)

For additional security of private software, a workspace can be sealed. See the discussion of *AWSFIX* in section 13 for details.

Error matrix. *□ERR*

The character matrix *□ERR* contains the last error message. Row 1 has the type of error. Row 2 has the name of the function, the line number (surrounded by brackets), and the line itself. Row 3 of *□ERR* has a slash to indicate where the error was found in row 2. The number of columns in *□ERR* varies according to the longest of the three rows.

The first row always shows the type of error actually encountered, but the location of the error as shown in rows 2 and 3 can be different from the actual location of the error under the following conditions:

1. If error trapping is in effect, the error is treated as an error in the pendent line of the trapping function.

2. If error trapping is not in effect and the error occurred in a line of a locked function or in an argument to execute, the location of the error is considered to be the most recent pendent line that is not an argument to execute or a line of a locked function. However, an error in a locked function that

uses trapping causes ⎕*ERR* to contain a line of the locked function. It is advisable for the locked function to localize ⎕*ERR* in order to protect its security.

Trap set. ⎕*TRAP integer*
The ⎕*TRAP* function sets, resets, or clears the trap line for the currently executing function. Use of ⎕*TRAP* from immediate execution mode has no effect. The argument must be an integer. If the integer is within the range of line numbers, that line becomes the trap line. If the number is 0 or exceeds the number of lines, trapping causes exit from the function. The trap can be cleared by ⎕*TRAP*←0. Once trapping is in effect, an error in that function, in ⎕ input, or any function invoked by it causes a forced branch to be taken to the trap line, and the trap state is cleared. Note that ⎕*TRAP* must be used to set the trap again before additional errors can be intercepted by that function. Hence a second error during processing of the trap routine results in either normal error processing or error processing by a function that invoked this one. If trapping is in effect, execution of functions can still halt as a result of a stop control. However, the trap then remains in effect for errors in immediate execution mode.

When a forced branch to the trap line occurs, at least one function will execute before an interrupt is detected. For complete security, the trap line can immediately reset the trap. In addition, at least one function is executed on the first line of a user-defined function before an interrupt is detected, thus allowing the function to set a trap without an interval of vulnerability to interrupts.

Location counter: ⎕*LC*
The variable ⎕*LC* contains a vector of all line numbers appearing on the state indicator. The numbers appear in the same order as in the)*SIV* display--that is, the numbers of the most recently invoked lines appear first. The first element is the number of the function line currently executing.

State indicator and variables. *matrix*←⎕*SIV vector*
The function ⎕*SIV* returns rows of the state indicator, including local variables. The argument must be a vector or scalar containing integers. The value returned is a character matrix containing a portion of the)*SIV* display selected by the right argument. ⎕*SIV* ⍳⍴⎕*LC* prints the entire *SIV* display (in either origin). If a value in the argument exceeds the range of appropriate row indexes for the *SIV* display, a blank line appears in the corresponding row of the result. Note that only entries for function lines appear on the state indicator--not execute arguments, quad input lines, or immediate execution lines.

MISCELLANEOUS SYSTEM COMMUNICATION

Accounting information. □*AI*
The variable □*AI* is a numeric vector of the following accounting information:

□*AI*[1] - A numeric encoding of the user's account number. For a character vector *V* containing the 7-character account number, the value of □*AI*[1] is generated in zero origin by
1001' *ABCDEFGHIJKLMNOPQRSTUVWXYZ*0123456789'⍳*V*
□*AI*[2] - Central processor time used.
□*AI*[3] - Total connect time.
□*AI*[4] - Total time the keyboard has been unlocked. Includes part of the time required for the system's response.
□*AI*[5] - The number of milli (thousandths of) System Resource Units (SRU's) used since entering APL.

Times are in milliseconds and are cumulative since signing on to APL.

Atomic vector. □*AV*
The vector □*AV* contains all 256 characters manipulable by APL. Note that the ordering of characters in □*AV* is system dependent, and programs that depend on the ordering of characters in □*AV* cannot be easily transferred to other APL systems. See the table in Appendix C to find positions of particular characters.

Time stamp. □*TS*
The value of □*TS* is a 7-element numeric vector expressing the current point in time. The elements are in the following order: the year (e.g., 1975), month (1 for January), day of the month, hour (0 to 23), minute, second, and millisecond. The last element is always 0 because the operating system does not report the time of day to millisecond precision.

Terminal Type. □*TT*
The value of □*TT* identifies the type of terminal in use. The value is a numeric scalar as follows:

1 - Correspondence
2 - Typewriter-pairing
3 - Bit-pairing
4 - ASCII-APL
5 - Teletype Model 33
6 - Full ASCII
7 - Batch ASCII
8 - Batch 501 Printer
9 - Teletype 38, arrangement 3
10 - CDC 713

Working area. □*WA*
The value of □*WA* is a 4-element vector of: the part of the maximum field length available, the current field length, the minimum field length the user wishes used, and the maximum field

length the user wishes used. The field length is the actual memory space occupied by the APL system and the workspace. The user can set constraints on the field length to be used in order to optimize performance (see Section 12). Attempts to reset the first two elements of ⎕*WA* have no effect. The maximum field length cannot be set to less than that which is currently required. Setting ⎕*WA*[4] to more than the user's validation limit or more than the field length limit imposed by the operator results in a *DOMAIN ERROR*.

Terminal mode. `vector←⎕TM'command'`
`vector←'dayfile message' ⎕TM 'command'`
The terminal mode function allows the following operations:

⎕*TM'SYSTEM'* Returns control to the operating system command processor.

⎕*TM'OFF'* Logs the user off.

⎕*TM'ABORT'* Terminates job with operating system abort error flag set.

Note that these commands do not cause the active workspace to be saved. The result returned is a vector containing a zero indicating that the operation was not recognized. If the right argument is an empty vector, nothing is performed, and the result is an empty vector. If a left argument is supplied, it is sent to the user's dayfile before the commands are executed. The user's dayfile is a log of the NOS control cards executed by the user and is available outside of APL.

Delay. `scalar←⎕DL seconds`
Causes execution to delay for the number of seconds requested. The delay does not involve consumption of central processor time. The result returned is the actual delay that occurred (usually slightly more than requested). The delay cannot be interrupted.

FORMAT SYSTEM FUNCTION

The function ⎕*FRMT* allows detailed control over column formatting. The function can be used in two forms:

```
matrix←A ⎕FRMT B
matrix←A ⎕FRMT (B1;B2; ... )
```

The second form uses a list structure generated by separating expressions by semicolons and surrounding the entire group of expressions with parentheses. The left argument is a character vector (or scalar) describing how successive columns of the right argument should be formatted. A scalar right argument or a scalar list element in the right argument is treated as a

one-element matrix, and a vector is treated as a one-column matrix. (To display a vector horizontally, reshape it to become a one-row matrix, or apply the ravel function to the result.) Arrays of rank greater than 2 are not allowed. The arrays in a list argument may have differing numbers of rows, which causes

blanks to be used in the lower portion of the result corresponding to the missing rows. If ⎕*FRMT* is the last operation on the line, the result is printed directly rather than actually forming a result, thus reducing the chance of a *WS FULL* error.

Format phrases. The left argument to ⎕*FRMT* is comprised of format phrases separated by commas. The following are the allowed forms for phrases:

[*n*]	[*q*]	*Iw*	Integer format. Same format as $(w,0)\text{▼}B$.
[*n*]	[*q*]	*Fw.d*	Decimal format. Same format as $(w,d)\text{▼}B$.
[*n*]		*Ew.d*	Exponential format. Same format as $(w,-d)\text{▼}B$. If $w \geq d+8$, field overflow will not occur and there will be at least one space separating the previous column.
[*n*]		*X*	Spaces.
[*n*]		*Aw*	Character format. *Aw* right justifies one character in a field of width *w*.
[*n*]		⎕*text*⎕	Literal format. Forms a field containing *text*.

Here *n* represents a number to be used as a repetition count, *q* represents a "qualifier" (described below), *w* represents a number to specify the width of the format field, and *d* represents a number to determine how many digits should be shown. Brackets are used to indicate parts that are optional. If no digits will appear after the decimal point in the result, the decimal point is omitted. If the repetition count is zero, the entire format phrase is ignored. If no repetition count is provided, 1 is used as the number of repetitions. Spaces may be used as desired in the left argument and have no effect unless they occur within pairs of ⎕ symbols or within a number (an error condition). Numbers are rounded to the precision required, and the number of digits shown is allowed to exceed the computer's precision (zeros are used to fill digits beyond the fifteenth). The following examples illustrate the use of simple format phrases:

```
      ⎕←M←⍉3 3⍴13 282 3.8 13.046 ¯22.52 0,○¯1E¯263 ¯2 1E30
 13    13.046 ¯3.141592654E¯263
282   ¯22.52  ¯6.283185307E0
  3.8   0      3.141592654E30

      'I4,F7.2,E13.5' ⎕FRMT M
 13  13.05 ¯3.1416E¯263
282 ¯22.52 ¯6.2832E0
  4   0.00  3.1416E30

      'A1,A2,A3,A4,A5' ⎕FRMT 1 5⍴'SPACE'
S P A  C  E
```

```
      ITEMS←4 7⍴'LATCHESHINGES BOLTS  TOTAL  '
      CODE←'FTX'
      QTY←18 34 102
      PRICE←2.45 1.20 .28
      TOT←P,+/P←QTY×PRICE
      '7A1,A3,⍞ |⍞,I5,F6.2,F8.2'⎕FRMT(ITEMS;CODE;QTY;PRICE;TOT)
LATCHES  F |   18   2.45   44.10
HINGES   T |   34   1.20   40.80
BOLTS    X |  102   0.28   28.56
TOTAL       |               113.46
```

The *I*, *F*, *E*, and *A* format primitives are value-using in the sense that each time one of these is performed it operates on a value from the right argument. There must be at least one value-using phrase if the right argument is not empty. As processing of a row of the right argument begins, the scan of the left argument begins at its first element. If the left argument is used up before the row of the right argument is completed, the scan of the left argument begins again at the left. When the row of the right argument is exhausted, the left argument is processed until a value-using phrase is encountered or until the scan encounters the end of the left argument.

If the information (including that required by qualifiers) to be placed in a field exceeds the width of the field, the field is filled with asterisks. Also, if a value in the right argument is of the wrong type for the format primitive (i.e., if numeric for *A* or if character for *I*, *F*, or *E*) the field is filled with asterisks and that value is bypassed.

Format qualifiers. Format qualifiers can be used with the *I* or *F* format primitives to further control the format. In cases where the qualifier depends on whether the number is positive, negative, or zero, the test considers only the part of the number that will be shown after rounding. For example, if *I* format were used with the numbers .01 and ¯.01 both would be considered to be zero. The following qualifiers are defined

R⍞*text*⍞	Background with which to pre-fill the field. The background is repeated from left to right as needed to fill the field.
C	Insert commas to group triples of digits to the left of the decimal point.
T	Change trailing zeros after the decimal point to blanks.
Z	Fill field by using leading zeros.
L	Left justify number in field.
M⍞*text*⍞	Place *text* to left of negative numbers. (Default is ⍞¯⍞.)
N⍞*text*⍞	Place *text* to right of negative numbers.
P⍞*text*⍞	Place *text* to left of nonnegative numbers.
Q⍞*text*⍞	Place *text* to right of nonnegative numbers.

N	*N*␣*text*␣	Fill entire field with blanks or with *text* (right justified) if negative.
B	*B*␣*text*␣	Fill entire field with blanks or with *text* (right justified) if zero.
P	*P*␣*text*␣	Fill entire field with blanks or with *text* (right justified) if positive.

If more than one qualifier of the same type is encountered in a format phrase, the rightmost one is used. (This allows the user to build variables containing prototype strings of qualifiers and then catenate on further qualifiers to deal with special cases.)

The formatting of a field can be considered to follow this procedure:

1. The field is pre-filled with blanks or the text specified by *R*␣*text*␣.

2. The number is rounded and formatted according to the format primitive and the *C*, *M*␣*text*␣, *N*␣*text*␣, *P*␣*text*␣, and *Q*␣*text*␣ qualifiers. Trailing zeros are replaced by blanks if *T* was specified, and leading zeros are added to the left (but to the right of the sign or text required by *M*␣*text*␣ or *P*␣*text*␣) if *Z* was specified. This augmented number is then moved into the right (or left if *L* was specified) of the pre-filled field.

3. Replacement text required by an applicable *N*, *B*, *P*, *N*␣*text*␣, *B*␣*text*␣, or *P*␣*text*␣ qualifier replaces the entire field.

The use of qualifiers is illustrated below:

```
      ⍝NEGATIVE NUMBERS IN PARENTHESES
      ROWS←2 15⍴'PROFIT (LOSS)  PER SHARE      '
      M←2 3⍴42E6 ¯4E6 18E6 3.14 ¯.32 1.26
      '15A1,3M␣(␣N␣)␣Q␣ ␣CF15.2' ⎕FRMT (ROWS;M)
PROFIT (LOSS)    42,000,000.00  (4,000,000.00) 18,000,000.00
PER SHARE                3.14          (0.32)           1.26
```

```
      ⍝DOUBLE ENTRY STYLE WITH TWO COLUMNS, N. C. FOR ZEROS
      V←24.61 ¯30.24 387.60 29.80 ¯52.48 0
      'B␣N. C.␣M␣␣N␣       ␣F14.2'⎕FRMT V
         24.61
 30.24
       387.60
        29.80
 52.48
        N. C.
```

```
      ⍝BACKGROUND FOR CHECK PROTECT
      '␣$␣,R␣*␣CF10.2' ⎕FRMT 3.14 328.54 50412.87
$******3.14
$****328.54
$*50,412.87

      ⍝BACKGROUND FOR TABLE OF CONTENTS,
      ⍝CHAPTER NUMBERS LEFT JUSTIFIED
      '␣CHAPTER ␣,LI2,R␣. ␣I40'⎕FRMT (7 8 9 10;9 92 328 552)
CHAPTER 7 . . . . . .9
CHAPTER 8 . . . . . 92
CHAPTER 9 . . . . . .328
CHAPTER 10. . . . . .552

      ⍝LEADING ZEROS FOR DATES
      DATES←4 3⍴3 7 72 4 4 73 1 16 76 12 1 75
      'I2,␣/␣,ZI2,␣/␣,ZI2'⎕FRMT DATES
 3/07/72
 4/04/73
 1/16/76
12/01/75

      ⍝LEADING ZEROS FOR MULTIPLE PRECISION REPRESENTATION
      'CI7,10CZI8' ⎕FRMT 1 4⍴1234 567890 003456 789012
 1,234,567,890,003,456,789,012

      ⍝CURRENCY SYMBOL AT LEFT,  CR TO RIGHT IF NEGATIVE
      'CM␣$␣N␣ CR␣P␣$␣Q␣   ␣F15.2' ⎕FRMT 32768 ¯911 1427.21
 $32,768.00
    $911.00 CR
  $1,427.21
```

Repetition. Groups of format phrases can be repeated by surrounding them with parentheses and prefixing with a repetition count. These repetition groups can in turn be nested within repetition groups. For example, '2(*F*2.0,*F*3.1)' means the same as '*F*2.0,*F*3.1,*F*2.0,*F*3.1' and '2(2(*F*2.0,*F*3.1),2(*F*4.1,*F*5.0))' is equivalent to:

```
      '2(F2.0,F3.1,F2.0,F3.1,F4.1,F5.0,F4.1,F5.0)'
```

NUMBER CONVERSION

Z←⎕*EXTRACT*'*characters*'

The ⎕*EXTRACT* function can be used to extract legal APL numbers from a character vector or scalar. The first element of the vector result tells the number of columns processed, and any remaining elements are any numbers encountered. The scan of the argument begins at its first element and proceeds to the right until a character is encountered that is not a blank or part of a number. If any illegal numbers (such as numbers with two decimal points) are encountered, a *SYNTAX ERROR* results.

Section 9. System Commands

System commands provide the same capabilities as some of the system functions and variables. The system commands are provided for compatibility with other APL systems. The main advantages to using system functions and variables instead of system commands is that the system functions and variables can be used in programs (system commands cannot). For more complete discussions of the operations performed by system commands, see the related system functions in Section 8.

GROUPS

The APL 2 system, unlike some other APL systems, does not have a distinct data type for "groups." However, the system commands allow a character matrix or a vector of names to be used for the same purposes as groups in the other systems. For example, if *GRPX* is a matrix of names, the command *)ERASE .GRPX* would erase *GRPX* and any objects referenced by the names in *GRPX*. The period in the command is required to indicate that objects referenced by *GRPX* are to be erased, not just *GRPX* itself. The general system convention for distinguishing groups is that all group names should begin with *GRP*. Matrices or vectors of names that do not begin with *GRP* can be used as groups, but they will not be listed by the command *)GRPS*. The names in the group definition can be preceded by a period, which causes them to be interpreted as a reference to another group. Any groups formed by the *)GROUP* command will be locked to prevent accidental use of the same variable for a different purpose.

)CLEAR (Equivalent to *⎕LOAD '*APL0 CLEARWS'*)

The command *)CLEAR* activates a clear workspace (described in Section 8) and erases all indirect access files and unties all direct access files that were tied during the APL session.

Table 9-1. Summary of Section 9.

)CLEAR
Activates a clear workspace.

)ERASE names
Erases specified functions and variables.

)SAVE [wsname] [:passwd] [/options]
Saves a permanent copy of the active workspace. Options may include *S*, *P*, *PU*, *IA*, or *DA*.

*)LOAD [*account] wsname [:passwd]*
Activates a copy of the specified workspace.

*)DROP [*account] wsname [:passwd]*
Removes a permanent workspace from the library.

*)COPY [*account] wsname [:passwd] [names]*
Protected copy of all global objects of classes 1, 2, and 3 or selected global objects from a stored workspace to the active workspace.

*)UCOPY [*account] wsname [:passwd] [names]*
Unprotected copy of all global objects of classes 1, 2, and 3 or selected global objects from a stored workspace to the active workspace.

*)LIB [*account] [name]*
Displays names, types, and sizes of all files, or displays detailed information about a single file.

)SYSTEM
Returns control to operating system command processor.

)OFF
Signs a user off.

)SI
Displays the state indicator.

)SIV
Displays the state indicator along with names of variables.

)FNS [letter]
Displays names of functions.

)VARS [letter]
Displays names of variables.

)GRPS [letter]
Displays names of groups.

)GRP group-name
Displays names in a specified group.

)GROUP group-name names
Forms a group having specified names.

)ERASE names (Equivalent to *□EX 'names'*)

Erases all global objects specified by the list of names. If a name is preceded by a period, the name is treated as the name of a group. The erasure erases the group itself (actually a matrix or vector of characters) and the objects referenced by the group.

)SAVE [wsname] [:passwd] [/options]
(Equivalent to *□SAVE '[wsname] [:passwd] [/options]'*)

The *)SAVE* command saves a copy of the active workspace under the name specified or under the name in *□WSID* if no name is given. The options are *S* (semiprivate), *P* (private, the default), *PU* (public), *DA* (direct access) or *IA* (indirect access, the default).

*)LOAD [*account] wsname [:passwd]*
(Equivalent to *□LOAD '[*account] wsname [:passwd]'*)

The *)LOAD* command activates a copy of a stored workspace. A password is required if the workspace has a password and is stored under another user number. After the workspace has been loaded, the system executes *□LX* if *□LX* is defined.

*)DROP [*account] wsname [:passwd]*
(Equivalent to *□DROP '[*account] wsname [:passwd]'*)

The *)DROP* command removes a stored workspace or other file from a library. If the workspace is in another user's library, a matching password must be given if the stored workspace has a password. The user must also be authorized to alter the existing file.

*)COPY [*account] wsname [:passwd] [names]*
*)UCOPY [*account] wsname [:passwd] [names]*

The *)COPY* command performs a protected copy of global functions and variables from a stored workspace to the active workspace. The *)COPY* command will not replace objects in the active workspace with objects from the stored workspace having the same names. The *)UCOPY* command performs an unprotected copy and will replace objects having the same names. If no list of names is given, all objects of classes 1, 2, and 3 are copied. If a name in the list is preceded by a period, the name is assumed to refer to a group and objects named in the group are also copied. The *□COPY* function can be used instead of *)COPY* if groups are not to be copied. The form is *['names'] □COPY '[*account] wsname [:passwd]'*.

)*LIB* [**account*] [*name*] (Equivalent to □*LIB* '[**account*][*name*]')

The)*LIB* command displays names, types, and sizes of all files the user is authorized to access, or, if a file name is specified,)*LIB* displays detailed information about that particular file. The format is the same as for □*LIB* (see Section 8).

)*SYSTEM* (Equivalent to □*TM*'*SYSTEM*')

The command)*SYSTEM* causes the user to leave APL control and allows the operating system command processor to execute subsequent commands. The active workspace is not saved.

)*OFF* (Equivalent to □*TM*'*OFF*')

The)*OFF* command signs a user off the system.

)*SI*
)*SIV* (Equivalent to □*SIV* ⍳0□*LC*)

The command)*SI* lists the state indicator, and the command)*SIV* lists the state indicator and all local variables. See Section 2 for the format of the display.

)*FNS* [*letter*] (Roughly equivalent to □*NL* 3)
)*VARS* [*letter*] (Roughly equivalent to □*NL* 2)
)*GRPS* [*letter*] (Roughly equivalant to '*G*' □*NL* 1)

These commands list the names of defined global functions, variables, and groups, respectively. If a letter is included, only names beginning with that letter or letters that follow that letter in the alphabet are shown. The command)*GRPS* lists variable names that begin with *GRP*.

)*GROUP group-name names*

The command)*GROUP* defines a group, extends a group, or erases a group definition. Groups are actually represented as character matrices. If the group-name itself is the first name in the list of names, any previously defined group is extended by the addition of the remaining names. If no names are given, the group definition is erased but objects named by the group are not erased. Names listed in the command can be preceded by a period in order to include a period in the group definition (to indicate the name refers to another group).

)GRP grpname (Equivalent to *grpname*)

The command *)GRP* displays the definition of the indicated group. If the group is not defined or is not a character matrix or vector, an error message is given.

Section 10. File System

This section discusses files from the APL user's point of view. The APL system supports two distinct types of files: APL-structured files, and coded files. The use of files enables programs to deal with large quantities of data that would not fit into a workspace, and files also provide a convenient way for programs to communicate with one another.

APL-STRUCTURED FILE CONCEPTS

An APL-structured file is a collection of APL arrays with each array identified by a nonnegative integer. The following example shows creation of a file and writing and reading a few records (arrays) of the file.

```
)LOAD  *APL1 FILESYS (File system functions are
                      loaded from APL1.)

'SAMPLE' FCREATE 9    (The FCREATE function is used
                       to create a file with the name SAMPLE
                       and with 9 as its number.)

'RECORD 3' FWRITE 9 3 (The left argument is written
                       to file 9 as record 3.)

(3 3⍴⍳9)FWRITE 9 1

(2 3⍴'□') FWRITE 9 28

 FREAD  9 1           (The records can be read in
1 2 3                  any order.)
4 5 6
7 8 9
```

Table 10-1. Summary of File Functions.

'filename [:passwd] [/options]' FCREATE fnum
Creates a file. Options are *DA*, *C*, *WR*, *S*, or *PU*.

array FWRITE fnum[,rnum]
Writes *array* on file number *fnum* as record *rnum*.

result←FREAD fnum[,rnum]
Reads the record numbered *rnum* from the file numbered *fnum*.

FRDEL fnum[,rnum]
Deletes record *rnum* from file *fnum*.

rnum←FFREE fnum
Returns the least record number not presently in use in file *fnum*.

*'[*account] filename [:passwd]' FPACK fnum*
Condenses file by eliminating lost and unused space.

FPOS fnum,rnum
Sets position of file *fnum* to *rnum*.

result←FSTATUS fnums
Returns the status of all files specified by the right argument. The result is a vector or matrix according to whether the argument is a scalar or vector. Columns are: (1) largest record number, (2) current position, (3) file size, (4) unused space, (5) lost space, (6) space not used because record sizes not divisible by 64, (7) 1 if coded file, (8) 1 if DA type, (9) 1 if absent record encountered by last read attempt.

PSTATUS
Prints status information (with descriptive headings) for all active files.

result←FNAMES
Returns a matrix of user numbers and names for all tied files.

result←FNUMS
File numbers in use for tied files.

FRETURN fnums
Unties specified direct access files and erases specified indirect access files.

FUNTIE fnums
Unties files in right argument. This leaves a permanent copy.

FERASE fnums
Erases all files specified by right argument. Erasure affects active file and for DA type also affects permanent file.

*'[*account] file-name [:passwd] [/options]' FTIE fnum*
Ties a file with specified options--*RD* for read only (other users can read at the same time), and *RM* for read-modify (another user can modify at the same time).

result←CFREAD fnum[,rows,columns]
Coded read. Result is a vector or matrix of characters or a numeric scalar--1 for end of record, 2 for end of file, 3 for end of information.

array CFWRITE fnum
The left argument is written to the coded file *fnum*. The argument should be a character scalar, vector, or matrix, or integers--1 to write end of record or 2 for end of file.

integers CFPOS fnum
Positions file. Operations indicated by first integer are: 0 for rewind, 1 for skip record, 2 for skip file, 3 for skip to end. Second integer for skip record or skip file may be included as repetition count.

jobname←CSUBMIT fnum[,type]
Submits the coded, indirect access file *fnum* as a batch job and erases the active copy.

```
    FREAD  9 28
□□□
□□□

    FREAD 9 3
RECORD 3
```

After the above steps, the user can store the file (using *FUNTIE* 9), an operation analogous to saving a workspace. The user could then sign off the system. The information in the file would remain intact and could be accessed or modified at a later time.

File limits. Individual file records are allowed to be as large as desired. However, user numbers have associated restrictions that may limit the total number of files, the total size of all files, the size of individual files, and whether the user can create direct access files.

Tied files. It is usually more convenient to use numbers within a program to identify a file rather than using the file name. All file operations require this file number. The number is tied to the file when the file is created using *FCREATE* or when a previously stored file is accessed using the *FTIE* function. Once

a file has been assigned a number, the file is said to be tied. The file can be released by using the *FUNTIE* operation, the *FRETURN* operation, by erasing the file using *FERASE*, by signing off from APL, or by typing)*CLEAR*. However, files remain tied when another workspace is loaded.

Accessing file functions. The functions described in this section are ordinarily stored under the user number *APL1* in the workspace *FILESYS*. Before file operations can be performed, the functions must be obtained from APL1 by loading the entire *FILESYS* workspace or by copying selected functions from *FILESYS*. All functions in *FILESYS* are independent, and you need copy only those functions you intend to use. The following examples show various ways that copies of the file functions can be obtained.

```
)LOAD *APL1 FILESYS
⎕LOAD '*APL1 FILESYS'
)COPY *APL1 FILESYS .GRPPRIM (A group that excludes
                              documentation)
)COPY *APL1 FILESYS FTIE FREAD
```

The file functions use the system function ⎕*FI* to perform all file operations. The function ⎕*FI* could actually be used directly, but it is usually more convenient to use the functions in the *FILESYS* workspace. Most of the functions in the *FILESYS* workspace are locked so that error processing will be more convenient. Users who wish to learn how to use ⎕*FI* directly can discover all details about ⎕*FI* by studying the definitions of the locked *FILESYS* functions below:

```
∇A FPACK B [1] A ⎕FI 0,B∇

∇A FCREATE B [1] A ⎕FI 1,B∇

∇A FWRITE B [1] A ⎕FI 2,B∇

∇Z←FREAD B [1] Z←⎕FI 3,B∇

∇FERASE B [1] B ⎕FI 4∇

∇FRDEL B [1] ⎕FI 5,B∇

∇Z←FSTATUS B [1] Z←B ⎕FI 6∇

∇Z←FNAMES [1] Z←⎕FI 7∇

∇Z←FNUMS [1] Z←⎕FI 8∇

∇FUNTIE B [1] B ⎕FI 9∇

∇A FTIE B [1] A ⎕FI 10,B∇

∇FPOS B [1] ⎕FI 11,B∇
```

```
∇A CFWRITE B [1] A ⎕FI 12,B∇

∇Z←CFREAD B [1] Z←⎕FI 13,B∇

∇A CFPOS B [1] ⎕FI 14,B,A∇

∇Z←CSUBMIT B [1] Z←⎕FI 15,B∇

∇Z←FFREE B [1] Z←⎕FI 16,B∇
```

In addition to the basic functions in the *FILESYS* workspace, the workspace *FILES2* contains additional file functions that are based on the functions in *FILESYS* and perform more complicated operations.

Active and stored files. APL-structured files are ordinarily indirect access files unless the user specifies otherwise at the time of creation. This means that when the file is tied, the system makes a copy of the stored file. All reads and writes actually interact with this active copy. To save the file as a permanent stored file, an *FUNTIE* is required. Signing off from APL, typing)*CLEAR*, or a telephone disconnect (assuming the RECOVER command is not used) causes the active file to be erased. One advantage of having a separate active copy is that no damage can be done to a stored file if a series of file updates is not completed. For example, suppose that a program writes a record to indicate that a transfer of funds was made from one account to another on a certain date, then the program revises two records containing the balances of those accounts. If the program were to halt in the middle of the sequence of operations (due to a system problem or telephone disconnect), the transactions recorded in the file would be inconsistent with the balances in the file. This causes no problem when indirect access files are used because the inconsistent information is in a temporary file and the stored file is in the same state it was when it was tied.

For some applications that use indirect access files, it may be desirable to perform an *FUNTIE* and an *FTIE* at intervals of about every ten minutes in order to minimize the amount of new information that would be lost in the event of a system problem.

Forms for file names and passwords. File passwords and file names must be composed of 1 to 7 of the letters *A* to *Z* and digits 0 to 9 and must not contain any embedded blanks. File names should be distinct from names used for other files or workspaces. Use of the same name will result in an error message when an attempt is made to untie the newly created file. (For a direct access file, the error occurs when *FCREATE* attempts to create the new file.)

Range for file numbers. File numbers can be any nonnegative integers not greater than 131071.

FILE SECURITY

A file is owned by the user who created it. The owner is allowed to alter the file in any desired manner, but the owner can control access by other users through the following controls:

1. The file *category* is ordinarily *private*. *Private* files cannot be accessed by other users unless their user names have been given explicit access permission by use of the PERMIT command (see Section 13). Alternatively, the file can be assigned a *category* of *semiprivate* or *public*. Either of these *categories* allows other users to access the file if they know the password, the name of the file, and the user name under which it was stored. The □*LIB* command will reveal to another user the names of files that are *semiprivate*, *public*, or that are *private* and have been explicitly made accessible to the other user. To make a file *public* or *semiprivate*, use the options *PU* or *S* when the file is created, or use the CHANGE command to change the *category*. When the □*LIB* function is used with a file name, the result shows when the file was created, when it was last changed, and when it was last accessed. In addition, for *semiprivate* and *private* files the system retains the number of accesses and the time of the last access for each user of the file. This information can be displayed by use of the CATLIST command (see Section 13).

2. The file can be given a password. Only users who know the password can use the file; however, the owner of the file is never required to provide the password. The password can be assigned when the file is created, or the password can be assigned or changed by use of the CHANGE command (see Section 13).

3. The file *mode* can be used to control the type of operation another user can perform. For files created by APL (including workspaces) other users are ordinarily allowed to read the file (assuming the password and *category* do not exclude them) but are not allowed to alter or destroy the file. Other users can be given permission to alter the file by specifying the *WR* option (for *write*) when the file is created. For *private* files, this mode has no significance because when other users are given explicit access permission via the PERMIT command, the permitted access mode for each user becomes that expressed in the PERMIT command. For *semi-private* files, the general access *mode* is applicable to most users of the file, but an overriding access *mode* can be specified for individual users by use of the PERMIT command. For example, most users might be allowed to read the file, while a few

selected users might be allowed to alter it. The general mode allowed for other users can be changed after the file has been created by use of the CHANGE command. For APL-structured files the mode should be write or read-modify, while for coded files it should be write or read.

4. Files can be accessed by other users through locked functions which can provide extremely general control over the permitted operations. For example, the locked function can prohibit alteration of the first five records of the file, or, it can prohibit adding records that are not vectors of 4 integers. The success of locked functions as a security measure rests on preventing the user from learning the file name, the user number, or the password, and preventing him from accessing the file directly. To assure this, the locked function should not call other functions (except those local to itself) lest someone substitute a subversive function having the same name. In particular, □*FI* should be used directly rather than using FTIE. (A subversive FTIE could print its arguments and thus reveal the file password). Also, □ input should not be used while the file is tied, and the file should be untied prior to exit from the function. To ensure that the file will be untied, use □*TRAP* to specify a trap line that will release the file prior to exit.

Note that the file *category*, *password*, and *mode* are independent restrictions on access by other users. Each of these further restricts the type of access permitted to others. Unless different options are specified when the file is created or the controls are changed, the APL system selects *private* as the file *category*, assigns no password, and selects read or read-modify *mode* (depending on whether the file is coded or APL-structured type, respectively).

APL-STRUCTURED FILE OPERATIONS

Sequential file operations. The file operations that ordinarily require a record number can also be used without specifying the record number. When this is done, the record number used is the current file position (available in the result of *FSTATUS*). The file position can be reset using *FPOS* and is incremented by each successful read, write, or deletion. When a file is tied or created, the position is initially zero. For example:

```
'XRAY'FTIE 5  (The file position is zero.)
Z←FREAD 5  (Record 0 is read; the position becomes 1.)
K FWRITE 5  (Record 1 is written)
Y FWRITE 5 (Record 2 is written)
W FWRITE 5  (Record 3 is written)
```

When a record number is provided for the operation, the file position will be set one greater than that number if the operation succeeds.

File create: *'file-name [:passwd] [/options]' FCREATE fnum*
The file create function can be used to create a file and specify options about the type of file. When the file is created, it is tied to the file number *fnum*. In addition to the name of the file, the left argument may include the password the file is to have. Examples of file creation follow:

'FILE1' FCREATE 11	(A file named *FILE1* with 11 as its number.)
'FILE2: SESAME'FCREATE 2	(A file with *SESAME* as its password.)

The list of options can include any of the following separated by spaces: *DA*, *C*, *WR*, *S*, or *PU* (to specify *direct access*, coded, *write mode*, *semiprivate*, or *public*).

File write: *array FWRITE fnum[,rnum]*
The *FWRITE* function writes its left argument on the file having *fnum* as its number as the record having *rnum* as its record number. This will replace any existing record in that file previously having that record number.

File read: *result←FREAD fnum[,rnum]*
The *FREAD* function reads from the file having *fnum* as its file number that record having *rnum* as its record number. If that record does not exist, an empty numeric vector is returned, and the file status (see *FSTATUS*) will indicate that the last read attempt encountered a nonexistent record.

File record delete: *FRDEL fnum[,rnum]*
The *FRDEL* function deletes the record *rnum* from file *fnum*. If the record was absent already, nothing is done (except that the file position changes) and no error results.

Free record number: *rnum←FFREE fnum*
The *FFREE* function returns the first free (unused) record number for file *fnum*. This is a useful way to select the record number for a new record when the application does not require a particular ordering of the records.

File positioning: *FPOS fnum,rnum*
The function *FPOS* sets the position of the file identified by *fnum* to record number *rnum*.

File status: *result←FSTATUS fnums*
The file status function returns various information about the condition of files identified by file numbers in the right

argument. If the argument is a vector, the result is a matrix having a row for each file number in the right argument. If the argument is a scalar, the result is a vector of information about the single file. The columns of the result contain:

Column	Contents
1	Largest record number currently in use or 1 if the file is empty.
2	Current file position.
3	File size in words.
4	Unused space in words.
5	Lost space in words.
6	Space not used because of record sizes not being divisible by 64. (This space is called "tails" because it resides at the tail ends of physical record units.)
7	0 if APL-structured file, 1 if coded type file.
8	0 if indirect access file type, 1 if direct access file type.
9	0 if last read attempt succeeded, 1 if the record was absent (APL structured files) or too long (coded files).

Note that only columns 7, 8, and 9 are meaningful for coded files. All columns will be zero if the file is not tied.

The largest record number does not take account of records that have been deleted. That is, the largest record number is the largest number currently in use for records that actually exist.

Print status: *PSTATUS*
The *PSTATUS* function prints the information returned by *FSTATUS FNUMS* along with the file names. The information is given in a descriptive format and is thus a convenient way to discover the status of all tied files if you do not remember the meanings of the columns in the result from *FSTATUS*. The following example illustrates the format used.

```
      PSTATUS
NAME          NUMBER LAST R  POS  SIZE  UNUSED  LOST  TAILS
 COMTIME          14    8     0   768     64      0     397
 LIB               2    1    14   256      0      0      98 DA
*A123456 SYSGEN   45   CODED FILE
 REFMAN7           1    94    0 80384    2496   7744    3233 DA
```

File names: result←*FNAMES*
The *FNAMES* function returns a matrix of names (and user numbers) of files currently tied. The number of columns in the matrix is always 16. For example,

```
      FNAMES
SAMPLE1
ALGEBRA
*A123456 FILE1
```

File numbers: result←*FNUMS*
The *FNUMS* function returns a vector of numbers in use for tied files. The order is the same as the order of file names in the result from *FNAMES*.

File untie: *FUNTIE* fnums
The *FUNTIE* function unties all files for which their file numbers appear in the vector or scalar right argument. This produces a permanent stored copy of each file. The new permanent copy will replace any previously existing file having the same name, unless the active file was newly created. To untie a newly created file when the same name is already in use for another stored file, first use □*DROP* to remove the old file. If any of the files specified in the argument is not tied, nothing is done and an error message results. To untie all tied files, use *FUNTIE FNUMS*. For indirect access files, *FUNTIE* saves the file whether it has been changed or not. This modifies the date indicating when the file was last changed (see □*LIB*).

File return: *FRETURN* fnums
The *FRETURN* function behaves as *FUNTIE* for direct access files and behaves as *FERASE* for indirect access files. This frees the number of a currently tied file for other uses with a minimal impact on stored files. The use of this function is recommended for cleaning up any files that may have been accidentally left tied. File numbers in the argument that are not in use for tied files are ignored.

File erase: *FERASE* fnums
The *FERASE* function erases the active copy of the file but leaves any stored copy of the file. (See the section on direct access files for exceptions.) To remove a stored copy, use □*DROP*.

File tie: '[*account] file-name [:passwd] [/options]' *FTIE* fnum
The *FTIE* function gives the number fnum to the previously stored file having the indicated name. If no previously stored file having that name is found, an error message is given and no file tie results. If a user number is given, the stored file is sought under that user number rather than the one used when signing on to the system. The password need be given only if another user number was provided and a password was given to the file. Examples using *FTIE* follow:

```
'FILE5' FTIE 7          (A user ties one of his own files.)
'*A0Q1234 FILE6'FTIE 8      (A user ties a file belonging
                             to another user.)

'*A123456 FILE7 :SESAME' FTIE 9
```

Note that the options *DA* and *C* (for direct access or coded files) must not be provided to the *FTIE* function. These options are chosen when the file is created and can be altered only by making a copy of the file. If the file number or file name is in use for another tied file, an error message results. The list of options can include either of the options *RD* or *RM*. These options are discussed in later sections.

File pack: '[*account] filename [:passwd]' FPACK fnum
The *FPACK* function is designed for occasional use to condense a direct access file by eliminating lost and unused space. Ordinarily, the *FPACK* function causes the file to be tied, packed in place, and then untied. However, file damage may cause the file to remain tied in write mode. In this event, other file system functions (*FUNTIE*, *FREAD*, *FWRITE*, or *FSTATUS*) can be used to diagnose or correct the problem.

SPECIAL CONSIDERATIONS FOR CODED FILES

Coded files are the standard type of file on the operating system for information interchange between programs, card readers, printers, and so forth. Coded files are essentially intended for sequential access; replacement of records, except at the end, is not practical. Instead, such changes would ordinarily be made by copying the file and making the changes as the new file is produced.

Coded files consist of lines (essentially vectors of characters) which can be separated into groups by end of record marks. These groups can in turn be separated by end of file marks. At the end of the file is an end of information mark. The characters in a line of a coded file are restricted to the 64-character set. The 256 APL characters are translated into these 64 characters as shown in Appendix C. Briefly, the letters *A* to *Z* become A to Z, all symbols with approximate equivalents for an ASCII printer are translated into those equivalents, and all others become @. When translating from the 64-character set to APL characters, all symbols are represented by equivalents, and @ is represented as ⍓ (the symbol used for illegal overstrikes).

The functions *FTIE*, *FUNTIE*, and *FRETURN* have essentially the same meanings for coded files as for APL-structured files. However, special functions must be used for reading, writing, and repositioning coded files.

Creating a coded file. A coded file can be created using *FCREATE* by including *C* as an additional parameter. For example,

```
'PRINT :XXX/C'FCREATE 9
```

Coded read: result←*CFREAD* fnum[,rows,columns]
When the right argument contains only the file number, the result returned by *CFREAD* is a character vector containing the next line from the file, or if an end of record, end of file, or end of information was encountered, the result is the scalar integer 1, 2, or 3, respectively. The file position changes after each read so that the next read will give the next line of the file. The *FREAD* function cannot be used in place of *CFREAD* with a coded file. If a line is longer than 1280 characters, only 1280 characters are provided for each call to *CFREAD*, although the file is positioned so that the next call to *CFREAD* will be able to continue the same line. In this case the file status (see *FSTATUS*) will indicate that the last read attempt did not read the entire line.

The right argument to *CFREAD* may optionally include the number of rows and columns the result is to have. In this case, the result is a character matrix (unless an end of record, end of file, or end of information was encountered) containing multiple lines from the file. Lines longer than the requested number of columns are shortened by omitting any extra columns, and short lines are extended to the requested number of columns by extending with blanks on the right. The actual number of rows may be less than requested if there are insufficient lines in the file before an end of record, end of file, or end of information. When the right argument to *CFREAD* includes the number of rows and columns, lines longer than 1280 characters may be read by providing a sufficiently large number of columns.

Coded write: array *CFWRITE* fnum
The left argument to *CFWRITE* is written at the current position of the file. The left argument must be a character vector, scalar (which is treated as a one-element vector), or matrix, or a scalar or vector containing the integers 1, 2, or 3. A character scalar or vector produces one line in the file, whereas a matrix produces one line for each row of the matrix. However, a unit separator symbol (the *U* over *S* overstrike) embedded in the left argument also causes a new line to begin, just as it would if the array were displayed on a terminal. Trailing blanks in a line are removed. The integers 1 or 2 produce an end of record mark or end of file mark, respectively. A vector of integers can be used to produce a series of these marks. The file position is altered after each write so that subsequent writes will add information after that produced by the present one. Anything written to the file is automatically followed by an end of information mark. This has the effect of truncating the file if the write was not performed at the end of the file. The function *FWRITE* cannot be used for a coded file in place of *CFWRITE*.

Because of peculiarities of the operating system, a colon at the end of a line in a coded file will vanish, and two or more colons next to each other may be considered an end of line (depending on the position within the word where they occur). These problems can be avoided entirely by not using colons in coded files.

Coded file positioning: *integers CFPOS fnum*
The function *CFPOS* repositions the file according to integers in the scalar or vector left argument. The first element in the left argument indicates the action to be taken, and the optional second element may contain a repetition count.

Operation	Value
Rewind	0
Skip record	1
Skip file	2
Skip to end	3

The rewind operation positions the file at its beginning. The rewind and skip-to-end do not allow use of a repetition count. For the skip record or skip file operations, the repetition count may be negative to skip towards the beginning of the file. If no repetition count is given, a count of 1 is assumed. The skip record operation counts end of file marks as records. The skipping never goes past the end of information mark or the beginning of the file, even if the repetition count has not been satisfied.

Batch job submission: *Z←CSUBMIT fnum[,type]*
The coded file *fnum* is submitted as a batch job. The *type* may be 0 if batch output produced by the job should be discarded, or 1 if it should be printed or punched at the central batch site. If no type is specified, a default type of 0 (output discarded) is used. The file must be a properly constructed job file (see operating system reference manual). In particular, the first two lines must be a job card and account card. The file must not be direct access type. If the operation is successful, the active file vanishes as if *FERASE* had been used. The result returned is the job name assigned to the job. This name can be used with the ENQUIRE command (see Section 13) to determine whether the job has completed. Note that the number of concurrently executing deferred batch jobs allowed for a given user number is controlled by the system.

SPECIAL CONSIDERATIONS FOR DIRECT ACCESS FILES

A direct access file differs from an indirect access file in that all operations interact with the permanent file itself, not with an active copy. This has both advantages and disadvantages. One advantage is that a copy of the entire file need not be made by the system when the file is tied. One disadvantage is that a program can stop executing due to a system problem in the middle of a series of file writes, and the stored file can end up with contradictory information. Another disadvantage of direct access files is that write operations take a little longer (because the APL system does less buffering of information due to the risk of a system problem freezing the file in a temporary state).

To create a direct access file, include the parameter *DA* in the left argument to *FCREATE*. A direct access file may also be a coded file if desired--these two options can be chosen independently. The following are examples of direct access file creation:

```
'FILEX/DA' FCREATE 4
'FILEY: XYZ/DA S WR' FCREATE 5
'FILEZ/C DA' FCREATE 6
```

All operations with direct access files take the same form as for indirect access files, but because of the differences between the two file types, the file tie, untie, and file erase operations behave differently: A file tie to a direct access file does not make a copy of the file. An untie does not create the permanent copy, it merely releases the file number for use with other files and releases the file itself for access by other users. An erase removes both the active and stored copy of the file because they are the same thing. In addition, *)CLEAR* or a telephone disconnect cause an automatic *FUNTIE* of a direct access file (thus leaving a stored file) whereas an indirect access file would be erased.

If a telephone disconnect occurs, the file remains tied for 10 minutes. The operations that were in progress can be continued by use of the operating system RECOVER command (Section 13). However, logging on without using the RECOVER command will leave the file tied until the 10 minute period is over, possibly causing an error message indicating the file is busy.

SYNCHRONIZED FILE OPERATIONS

At present, it is not very practical for two users to update a single file at the same time. With an indirect access file the two users are actually updating separate copies of the same file, and whichever user unties the file last will create a stored file with his updates, but will replace any stored file just produced by the other user. The operating system does not allow two users to be tied to the same direct access file in write mode at the same time, so no conflicts can occur, but an error occurs if a second user attempts to tie the file. However, users can tie a direct access file in read mode (which allows other users to read the file at the same time) or read-modify mode (which means the user desires only to read the file but has no objection to another user writing to the file at the same time). To tie a file in read mode or in read-modify mode, include *RD* or *RM* (but not both) in the left argument to the *FTIE* function. For example,

```
'FILE1/RD'FTIE 9     (Read mode.)

'FILE2: SECURE/RM' FTIE 10   (Read-modify mode.)
```

These modes are allowed for indirect access files as well. Read mode can be used for APL-structured or coded files while read-modify mode is allowed only for APL-structured files.

FILE EFFICIENCY

Although many users need not concern themselves with the information presented here on file efficiency, users of very large files will find this information important. Use of a few fairly simple techniques can result in improved speed and reduced storage requirements.

First of all, each APL-structured file has an initial size of 64 words used for a table of available space. In addition, one word is required for each record number up to the last record number in use. This space is allocated in multiples of 64 words. These two factors combine to make it inefficient to store many files with only a few records in each rather than one file with many records. Also, it is inefficient to leave large gaps between record numbers as the unused numbers require an average of one word each.

Indirect access files grow in multiples of 64 words, but direct access files grow in multiples of a logical track (usually several thousand words, depending on the storage device used). There is consequently a considerable space advantage to using indirect access files for files smaller than several thousand words. The number of words required for a file that results from writing an array *B* is

```
4+(ρρB)+⌈(×/ρB)÷D
```

where *D* is the density of packing in the file--1 for floating point, 7.5 for characters, and 60 for boolean (See also section 12.). This size is then rounded up to a multiple of 64 words. Because records require multiples of 64 words, there is some saving in space if many little arrays can be packed together and written as a single record. In addition, actual transfers and operating system requests are reduced because no buffering of output is used for APL-structured files.

When records are erased or replaced by records of a different size, the APL system keeps track of any unused gaps in the file where records can be placed in the future. The total amount of this space in words is in column 4 of the result returned by the *FSTATUS* function. It may happen that the number of gaps exceeds the size of the table, in which case the smallest gap is removed from the table. This results in a certain amount of space becoming unusable, and the total amount of this lost space is in column 5 of the result returned by the status function. Lost space can also result in a direct access file if a telephone disconnect or system problem prevents the file from being untied (`⎕TM 'SYSTEM'`, `⎕TM 'ABORT'`, and `⎕TM 'OFF'` untie files properly), and if the *RECOVER* command is not or can not be used. All lost and unused space can be recovered by applying the *FPACK* function to the file. Because each record occupies a multiple of 64 words, some space is generally left unused. This space is returned in column 6 of the result from *FSTATUS*.

Details of the space required for coded files can be found in the operating system reference manual. Coded files have a speed advantage over APL-structured files when the information is accessed sequentially, the records are small, and the limitations of the 64-character set are not restrictive.

INTEGRITY OF DIRECT ACCESS APL-STRUCTURED FILES

File integrity refers to the ability of a file to retain internal consistency. Some file access methods render a file practically useless if a program operating on the file does not complete properly (due to a flaw in the program or a system problem). Every effort has been made in the design of the APL-structured file system to minimize the chance of such damage.

All alterations to an APL-structured file are performed immediately and thus occur in exactly the order requested. When multiple files are being updated, one file will not be several transactions ahead of another. A checksum is computed for each file record so that if the storage device corrupts the information and is unable to detect the error, the error will still be detected by the APL system. A system halt, program halt, or telephone disconnect will leave the file in a satisfactory state except that in the rare event of a system halt requiring a level zero deadstart within a minute of extending a direct access file, there is some chance of damage to newly created or replaced records.

File damage will cause an error message to be printed at the time it is detected. The damage will usually affect only one record of the file. If the file cannot be reconstructed, installation personnel can assist with restoring the file to its state the last time files were dumped to magnetic tape.

Note that a telephone disconnect or system problem that results in failure to untie the file may cause the information on file space utilization (unused space, lost space, and tails) to be incorrect. This does not hinder utilization of the file and can be corrected by copying the file or applying the *FPACK* function to it.

FILE EXAMPLES

The following sample functions taken from the workspace *FILES2* under user number *APL1* illustrate simple file operations. The first function, *FCOPY*, can be used to copy an APL-structured file. Such a copy might be made to convert the file from indirect access to direct access form or to compact the file by minimizing unused space. The left argument should be the character argument required to tie the old file, and the right argument should be the character argument required to create the new file. Note that the first line illustrates a simple way to select a file number that is not already in use.

```
      ∇FCOPY[□]∇
      ∇A FCOPY B;P;K;I;J
[1]    A FTIE I←1+⌈/0,FNUMS
[2]    B FCREATE J←I+1
[3]    K←(FSTATUS I)[1] ⍝ GET LARGEST RECORD NUMBER
[4]   L1:→(K<0)/L3
[5]    P←FREAD I,K ⍝ READ RECORD K FROM FILE I
[6]    →(FSTATUS I)[9]/L2 ⍝ IF ABSENT RECORD
[7]    P FWRITE J,K ⍝ WRITE RECORD K TO FILE J
[8]   L2:K←K-1
[9]    →L1
[10]  L3:FUNTIE I,J ⍝ UNTIE BOTH FILES
[11]   'COPY COMPLETE'
      ∇
```

The next function is useful for listing a coded file. The right argument may be the name of a stored file or the number of an active file. If a name is given, the file is tied, listed, then untied. If a number is provided, the file is listed beginning at its current position and is left tied.

```
      ∇CLIST[□]∇
      ∇CLIST B;K;L
[1]    →(0=0\0ρK←B)/L1 ⍝ IF FILE ALREADY TIED
[2]    B FTIE K←1+⌈/0,FNUMS
[3]   L1:L←CFREAD K
[4]    →(0=ρρL)/L2 ⍝ SCALAR INDICATES SPECIAL MARK
[5]    L
[6]    →L1
[7]   L2:→L3+2×L-1
[8]   L3:'-END OF RECORD-'
[9]    →L1
[10]   '-END OF FILE-'
[11]   →L1
[12]   '-END OF INFORMATION-'
[13]   FUNTIE(0≠0\0ρB)/K
      ∇
```

The next two functions are useful when a file is too large to list at a terminal but it is necessary to learn the general structure of the file. The function *FMAP* prints the structure of an APL file, and the function *CMAP* prints the structure of a coded file. Both functions allow a character argument or a numeric argument in the same manner as *CLIST*. If the file is already tied (for numeric arguments) the mapping begins at the current file position. *FMAP* prints record numbers and the types (*C* or *N* for character or numeric) and shapes of records that exist, or *ABSENT* for absent records. *CMAP* prints the number of lines in records and prints *EOR*, *EOF*, or *EOI* when an end of record, end of file, or end of information is encountered.

```
      ∇FMAP[□]∇
      ∇FMAP B;K;P
[1]    →(0=0\0ρK←B)/L1 ⍝ IF B IS NUMERIC
[2]    B FTIE K←1+⌈/0,FNUMS
[3]   L1:→(¯1≠1↑FSTATUS K)/L2 ⍝ IF FILE NOT EMPTY
[4]    'NO RECORDS'
[5]    →0
[6]   L2:'NUMBER, TYPE, DIMENSIONS'
[7]   L3:→(</2↑FSTATUS K)/L5 ⍝ IF FINISHED
[8]    P←FREAD K
[9]    →(FSTATUS K)[9]/L4 ⍝ IF READ FAILED
[10]   ¯1+(FSTATUS K)[2];0 1 0\'CN'[1+0=0\0ρP];ρP
[11]   →L3
[12]  L4:¯1+(FSTATUS K)[2];' ABSENT'
[13]   →L3
[14]  L5:FUNTIE(0≠0\0ρB)/K
      ∇

      ∇CMAP[□]∇
      ∇CMAP B;K;P;C
[1]    →(0=0\0ρK←B)/L1 ⍝ IF B IS NUMERIC
[2]    B FTIE K←1+⌈/0,FNUMS
[3]   L1:C←0
[4]   L2:→(0=ρρP←CFREAD K)/L3
[5]    C←C+1
[6]    →L2
[7]   L3:→(C=0)/L4
[8]    C;' LINE',(C≠1)/'S'
[9]   L4:'EO','RFI'[P]
[10]   →(P<3)/L1
[11]   FUNTIE(0≠0\0ρB)/K
      ∇
```

Section 11. APL Public Libraries

The standard APL release includes the following workspaces stored under the user name APL1:

APLNEWS News about the changes in the APL system as well as a list of reported bugs and requests for system changes.

FILESYS File system functions.

FILES2 Contains functions from *FILESYS* for primitive file operations as well as additional functions for more elaborate file operations.

CATALOG A guide to workspaces in the APL public libraries.

To learn how to use any of these workspaces, type a command of the form ⎕*LOAD'*APL1 *FILESYS'* and then type *DESCRIBE*.

APL PROGRAM LIBRARY STANDARDS

It is suggested that installations reserve the user names *APL*1 to *APL*999 for APL public libraries. Although these user names need not be defined in the system, they should not be used for other purposes. It is suggested that programs placed in these public libraries be of fairly general interest so that users will find it rewarding to browse through the various workspaces. Workspaces of interest only to a specialized group or course should be stored elsewhere.

Programs placed in the public libraries should be well documented. The available documentation may be entirely in the workspace or partly in the workspace and partly in a manual. In any case, the documentation should be readily available. The advantage of having the documentation in the workspace is that it will be immediately accessible. The disadvantages are that the documentation is slow to print and therefore tedious to read, and the format of the documentation is constrained by the APL character set. Generally, the amount of documentation determines whether it is practical to put the documentation in the workspace.

Documentation in the workspace should consist of functions or variables that describe the workspace. The documentation should be able to be printed with a standard APL terminal and should print within a standard 65 column page width. The following documentation variables or functions are suggested. Typing the name of the function or variable should cause the information to be printed.

ABSTRACT. Should contain a brief description of the contents of the workspace.

DESCRIBE. This should give the user further details than provided in the *ABSTRACT*. This should print the names of all functions intended for the user to use as modules along with a short description and names of related *HOW* functions (see below). If groups are defined in the workspace, describe them and their purposes.

HOW functions. If a function has the name *NAME*, detailed documentation of that function should have the name *NAMEHOW*. There is no point in giving a line-by-line description of the function. The APL program is already an excellent description of the separate steps. The *HOW* function should tell what the function does and how to use it as a module. In some cases it should outline major steps in the processing and describe the method used. References might be appropriate. Special limitations of the function should be discussed.

SOURCE. Should give the author's name, an inquiry name, and an inquiry address. The date when the workspace was contributed should be included.

CHANGES. Changes should be documented by a function or variable having a name of the form *CHANGES*092675 (so that the name includes the date of the changes).

GRPDOC. The group (locked matrix of names) *GRPDOC* should include names of all documentation variables and functions so that the user can readily erase them to make more space available in the workspace or reduce disk storage charges.

Even when most of the documentation is in a separate manual, the following variables or functions are required: *ABSTRACT*, *SOURCE*, *GRPDOC*, and *DESCRIBE*.

Section 12. Optimization of APL Programs

This section discusses some of the techniques that can be used to make APL programs perform better and run with lower demands on computer resources. It may seem out of place to discuss efficiency in an APL manual--after all, APL should free the user from being concerned with the nature of the particular computer being used--but the techniques discussed here may yield efficiency improvements as large as a factor of a hundred. To neglect discussing efficiency could leave many users with the mistaken impression that APL cannot perform well enough to be used for their problems.

Often, the question of efficiency calls to mind the fanatical programmer who constructs a program he considers efficient but who in doing so produces a totally incomprehensible collection of operations. It should be remembered that for many programs the programming time is so great that the only kind of efficiency worth considering is the sort that makes the program easy to understand, free of errors, and easy to change. Fortunately, a simple program is usually an efficient program. However, when improving the performance of the program does not coincide with simplifying it, the optimization should not be applied unless it is very important for the program to perform well.

As a very blatant example of misguided optimization, consider the following statement:

```
K←1,0⍴P←0,⌈/L←⍳Q←⍴R
```

This statement was probably contrived by someone who believed that the most efficient program was the one that required the smallest number of lines. The fact is, execution proceeds from one line to the next very rapidly compared to the time required to perform the extra steps needed to fit the operations in one line. The following statements are a more straightforward way to achieve the same results:

```
K←1
L←⍳Q←⍴R
P←0,Q
```

One way to estimate the relative time required for an expression is to count the number of operations required. (This method is fairly valid when the number of elements in arrays is less than about 20.) For this method of estimation, specification is not counted at all (it takes relatively little time). The one line version totals 6 operations while the three line version requires only 3 operations. The efficiency expert who wrote the one line version devoted extra time to adding three operations, which double the time required for execution. The one line version is harder to understand, is more likely to contain errors, and when changes are made, the rest of the line hinders revision. The one liner is thus a poor example of efficiency in all respects.

At this point it must be stated that much of the information in this section is relevant only to this particular APL system. Also, it may occur that something that is particularly slow now will become particularly fast in later versions of the system. Other versions of APL on other computers will often show quite different characteristics. In fact, according to Paul Berry (who wrote one of the first books on APL), the popular belief that one line programs are more efficient is based on a system for which this is true. An early version of APL on a small computer actually required considerable time to change from one line to the next because only one line at a time was kept in main memory. Although very few present users of APL ever used that particular system, its influence persists.

STORAGE REQUIREMENTS

Although the APL system allows a workspace of up to about 119,000 words (provided the user is validated to use that much main memory and the installation has that much), equivalent to 892,500 8-bit bytes, there are practical reasons to keep a workspace smaller. The operating system uses computer resources much more effectively when it runs programs requiring minimal amounts of central memory. Also, the "response time" for an interactive program to respond to a command requiring a trivial amount of processing increases somewhat with central memory requirements. In addition, minimizing storage requirements improves the chances that the same program will be able to run under another version of APL or on a computer with less central memory.

The vector ⎕*WA* contains information about the memory currently in use for the APL system and the active workspace. The field length is the amount of memory space currently in use. The APL system manages that memory space and at any given time some of the space may not be in use for functions, variables, and

other information kept by the APL system. The APL system evaluates storage requirements from time to time and resets its actual field length according to current needs. The user can set ⎕*WA* to specify the maximum and minimum field lengths to be used. Increasing the maximum and minimum field length generally reduces the central processor time used by APL to reorganize its storage, but as discussed previously, reduces the operating system efficiency. As a general rule of thumb, leave the minimum field length at its normal value, and set the maximum field length large enough to avoid *WS FULL* plus a little extra to prevent frequent storage reorganization. Incidentally, referencing the value of ⎕*WA* in a statement causes the APL system to reorganize its storage, so programs should not alter or read the value of ⎕*WA* too often or performance will be degraded.

Obvious techniques for minimizing storage requirements include using algorithms that minimize temporary storage, using local variables and local functions to assure automatic erasure of unneeded objects, and using ⎕*EX* to erase other functions that are no longer needed. ⎕*EX* can also be used to erase variables, but respecification (e.g., *A*←'') is faster. Files can be used to store functions and variables until they are required. ⎕*LOAD* can be used to load another workspace of functions and variables. Any variables that must be communicated from one workspace to the next can be placed in files--files remain tied when another workspace is loaded. Of course, any of these techniques can be overdone. Do not let the time spent performing these operations outweigh the storage they save.

The space in words required for an APL array *A* is

$$2+(\rho\rho A)+\lceil(\times/\rho A)\div D$$

where *D* is the number of elements packed per word--1 for floating point values, 4 for characters, and 32 for logical. Clearly, there is an advantage to using the internal logical representation if the values are ones and zeros. The system does not always use the logical representation when it could. For example, the scalar constants 1 and 0 are floating point, and 1+0 is floating point. However, the following functions always produce a logical result: $A\wedge B$, $A\vee B$, $A\nand B$, $A\nor B$, $A=B$, $A\neq B$, $A<B$, $A\leq B$, $A>B$, $A\geq B$, and $A\in B$. Also, the functions that restructure or rearrange their arguments always preserve the same type of representation, so $N\rho 0$ is floating point, while $N\rho 1\ 0$ is logical (because vector constants consisting of ones and zeros are packed as logicals). To assure that a result is logical, apply 1= to it.

Expressions like $A\leftarrow B\leftarrow C\leftarrow\iota 100$ do not cause three copies of $\iota 100$ to be produced. Actually, only one copy is kept. However, subsequently altering an element of *A*, *B*, or *C*, (e.g., *A*[3]←9) will cause a separate copy to be made. Similarly, arguments to

functions are not actually copied unless an attempt is made to alter them using indexed specification. Unlike most other APL systems, using function arguments rather than global variables incurs no storage penalty.

The operation *A/⍳B* is treated as a single function to avoid generating *⍳B* when only a few elements will actually be selected. This combined operation is somewhat faster and uses considerably less storage for an important class of cases.

Storage requirements for programs are too complicated to discuss in detail. As a rule of thumb, unless you make a special effort to put a lot on each line, figure that an average statement takes about 10 words of storage. The first time a statement is executed it is converted to an internal form for more efficient execution. In the internal form the function almost always requires somewhat more space. The storage overhead per line of a function averages about 3.5 words for lines without labels and 4.5 words for lines with labels.

The APL system keeps a "symbol table" in the workspace containing all names of functions, variables, and labels. Once a name has been used (even if the use resulted in a *VALUE ERROR*) the name remains in the symbol table. The space used by names that are no longer needed can be recovered by copying all objects into a truly clear workspace. The recommended procedure is:

```
)CLEAR                    (Obtain a clear workspace.)
⎕ENV←0                    (Copy global objects.)
(1 2 3 4 ⎕NAMES 'OLDWS')⎕COPY 'OLDWS'
⎕ENV←1                    (Restore to normal value.)
⎕SAVE 'NEWWS'
```

This procedure will also recover space in workspace areas other than the symbol table in some circumstances.

Space can be conserved in the symbol table by using names consisting of a single symbol whenever possible. Space can also be conserved by using the same name in several functions for local variables or labels. A common convention is to use the letters *A* to *Z* for local variable names and use *L1*, *L2*, and so forth for labels.

CENTRAL PROCESSOR TIME

For many programs the main optimization problem is to minimize central processor time. First of all, one of the primary determinants of central processor time is the appropriatness of the algorithm used. The algorithm should be appropriate to the data to be processed and appropriate to APL. Computer literature is filled with algorithms that are

"efficient" for other languages but which perform miserably in APL. Often a straightforward translation of a program from another language gives a program that performs poorly because it fails to take advantage of the more powerful APL functions.

For most operations in APL the time required for the operation can be separated into a per-element time required to process each element of the arguments and result plus a setup time required for interpreter overhead, to check the arguments for compatibility of dimensions, to compute the result dimensions, and allocate space for the result. The time per element varies considerably with the complexity of the operation. The sine function, for example, requires far more time per element than addition. The time also depends some on the way the values are stored; operations defined only for logic values perform better if their arguments are internally represented as logical type, and arithmetic operations are faster for the floating point internal type. The setup time varies far less from function to function than the time per element.

For many functions the setup time is on the order of 25 times as great as the time per element. This means that the setup time is negligible when thousands of elements are to be processed, but the setup time constitutes about 95 percent of the time when only one element is being processed. For most programs, the setup time limits speed more than the time per element. Thus the first step to optimization is to minimize the number of operations to be performed. For example, if ρX is used many times in a function, it would be worthwhile to assign the value of ρX to a variable (assigment requires negligible time). Often a branch statement can be added to skip steps that are not required except in special cases.

When the arrays used have a large number of elements, the operations should be chosen to minimize the number of elements processed. For example, if V is a vector of 5000 characters, a few elements can be selected from V using $N\uparrow M\downarrow V$ (which might process about 5000 elements) or using $V[J+\iota K]$ (which would process only a few elements). The second approach is much more efficient. Similarly, rather than extending a vector by catenating one element at a time, it might be preferable to extend it with a large number of elements and then respecify the elements one at a time using indexed specification.

It is commonly believed that APL branching for looping is slow. Actually, looping is fairly fast by itself but is usually a sign that the program is performing operations one element at a time--the amount of time required is mainly due to the number of operations being performed. Actually, looping is sometimes a very efficient way to perform an operation, especially if the number of iterations required for normal cases is small and the alternative requires more operations than are used in the loop.

On some APL systems central processor time can be saved by catenating output together and then printing it in a batch rather than as it is generated. However, for this APL system it is more efficient to print the output as it is produced.

The following chart gives approximate timings for various operations. Be forewarned that these timings are approximate and will vary with the particular computer used and the internal workspace configuration. Times are expressed in terms of *T*, the time per element for addition.

Time range	Operations
0 to *T*	Time per element for *A*∧*B*, *A*∨*B*, and ~*B* for logical internal representation
T to 5×*T*	Setup time per statement to be evaluated Time per element for most scalar and mixed functions
5×*T* to 25×*T*	Time per element for complicated functions such as *A*○*B*, *A*⍟*B*, *A*⌽*B*, and *A*[*B*] Time required for an unnecessary set of parentheses in a statement Time required to evaluate a constant other than 0, 1, 2, .5, ¯1, and ' '. Extra time per local variable for a function call →*B* *A*←*B*
25×*T* to 125×*T*	Call to a user defined function with a few local variables Setup time for primitive functions

Section 13. Operating System Features for APL Users

This section discusses a few operating system commands of interest to users of APL. The discussions cover only the more important details. Further information can be found in the time-sharing reference manual or volume 1 of the operating system reference manual. Be aware that the descriptions here are less detailed and may not be as up to date as the other manuals. Most of the commands discussed can be used as timesharing commands or batch job control cards. However, they cannot be used while in APL. Use the commands before issuance of the APL command, or use *⎕TM'SYSTEM'* to leave APL to use these commands. Note that none of these commands allow embedded spaces.

If NAM/IAF is not used for communications with terminals, some special precautions must be observed for these commands. When an ASCII terminal is used, it may be necessary to first use the TERM command (see time-sharing reference manual) in order to produce legible output when using an APL type element. Also note that the "equals" symbol used in some of these commands may not print as = on ASCII terminals (depending on the terminal type and the type of terminal specified in the TERM command). See Appendix F.

HELLO

The HELLO command allows you to sign on again with a different account number.

BYE

The command BYE is the correct way to sign off the system when not in APL. This is equivalent to the APL command *⎕TM'OFF'* or *)OFF*.

PASSWOR

The PASSWOR (pronounce it "password"--all operating system commands have names of seven letters or less) command allows you to change the sign-on password associated with your user name. The form for the command is:

PASSWOR,old,new

where *old* represents the old password and *new* represents the new password. If there was no old password it will look like:

PASSWOR,,new

RECOVER,*number*

The RECOVER command can be used to return to the state just before a disconnect or system malfunction occurred. The use of this command prevents loss of the active workspace or active files. The command is allowed only when the system prints RECOVER/SYSTEM at the end of the sign-on procedure. If you have already proceeded beyond that point and wish to initiate recovery, type HELLO to begin the sign-on procedure anew. The *number* you provide in the RECOVER command should be the terminal number that was printed after the previous sign on. (That is, the terminal number in effect for the session that terminated abnormally.) After you type the RECOVER command, the system may print RECOVERY IMPOSSIBLE, which indicates that the system malfunction was too serious to allow recovery, that too much time has elapsed (recovery information is retained for ten minutes), you signed on with a different user number, or that you gave an incorrect terminal number. When the RECOVER command is successful, the recovery information is destroyed and the system prints various information about the status at the time of disruption. Press the RETURN key to continue (or type STOP to exit from APL). The recovery is sometimes imperfect. Some output may be lost, and the next input request may cause a question mark to be printed, and any special APL symbols used in the input may be translated incorrectly. Do not perform the recovery on a different type of terminal from that in use when the disruption occurred or the APL system will translate input and output incorrectly for that terminal. After a recovery, the next interrupt from the keyboard will terminate APL. To avoid this, perform the following steps after recovery (unless files are tied)

```
      )SAVE wsname
      )SYSTEM
APL,WS=wsname
```

SETTL,*number*

Sets the CPU time limit to *number*. This can be used before entering *APLUM* to prevent a *TIME LIMIT* error from occurring. The *number* should be the desired time limit in octal. In order to be meaningful, the time limit should be at least 10 (octal) and the last digit should be a zero. The time limit must not be set to more than the remaining allowance for the session. (You can use the HELLO command to start a new session and get a fresh allotment of CPU time.)

S,*number*

This command is meaningful only immediately after the system has printed *SRU LIMIT*. This command extends the SRU limit by the requested amount. If you type anything other than S,*number*, a forced exit from APL will occur and the active workspace will be lost. If you have used up the entire SRU allotment for the session, hang up the phone and then sign on again and use the RECOVER command.

T,*number*

This command is meaningful only immediately after the system has printed *TIME LIMIT*. The *number* has the same significance as for the SETTL command. If you type anything other than T,*number*, a forced exit from APL will occur and the active workspace will be lost. If you have used up the entire CPU time allotment for the session, hang up the phone and then sign on again and use the RECOVER command.

CHANGE

The CHANGE command can be used to change the name of a file (which includes workspaces), its password, category, or access modes permitted to other users. The following examples show simple forms of the command.

CHANGE,*newname=oldname*
Changes the name from *oldname* to *newname*.

CHANGE,*filename*/CT=*category*
Changes the category. The *category* specified may be P for private, S for semiprivate, or PU for public.

CHANGE,*filename*/M=*mode*
Changes the mode. The *mode* specified may be R for read, W for write, MODIFY for modify, or RM for read-modify. (Other modes exist but are not of interest for APL users.)

CHANGE,*filename*/PW=*password*
Sets the file password. The *password* may consist of 1 to 7 letters or digits.

ENQUIRE,JN=*jobname*

This command can be used to determine the status of a job submitted using the *CSUBMIT* function (discussed in Section 10). If the response indicates the job is not in the system, this usually indicates that it has completed or is presently being printed.

PERMIT

The PERMIT command can be used to give another user access to a private file or to specify the permitted access mode for a particular user of a semiprivate file. The form of the command is:

PERMIT,*filename*,*account*=*mode*,*account*=*mode*, ...

The mode for each account number determines the type of access allowed. Meaningful modes for APL users are R for read, W for write, or RM for read-modify.

CATLIST

The CATLIST command can be used to examine access information about an individual file. The following examples show how to find information not provided by the APL ⎕*LIB* function:

CATLIST/LO=F,FN=*filename*
Similar to ⎕*LIB*'*filename*' but also gives the password and count of the number of accesses.

CATLIST/LO=FP,FN=*filename*
Gives access information for each user who accessed the specified private or semiprivate file. The information printed includes the number of accesses by each user, the access mode allowed for each user, and the date and time of the last access by each user.

LIMITS

The LIMITS command causes validation limits for the account number currently in use to be printed. Any numbers in the output that are followed by a B are expressed in octal (base 8). The APL functions base-value and represent can be used to convert between octal and decimal. For example, 70000B can be converted to decimal using 8⊥7 0 0 0 0, and 32768 can be converted to octal using (6⍴8)⊤32768. The following are the limits that are important to APL users:

TL = CPU time limit in 10's (octal) per session. Append a zero to the right of the number to find the CPU time limit in octal seconds. In addition, there may be a smaller time limit per session. This other time limit per session can be overridden by using the SETTL command or by using the T,*number* command after a *TIME LIMIT* error occurs. If you have consumed your entire CPU time limit for the session, you can use the operating system HELLO command to get a new CPU time allotment, or hang up, sign on again, and use the operating system RECOVER command.

CM = Maximum central memory field length. Append two zeros to the right of the number to find the central memory limit in octal words. Note that a more stringent restriction can be imposed on all timesharing users by the computer operator. This second restriction may vary according to the time of day.

DB = The number of jobs allowed for the given user. The *CSUBMIT* function (see Section 10) is not allowed to submit additional jobs if the total number of jobs for that account number already equals or exceeds this parameter. The count of jobs includes the program attempting to use the *CSUBMIT* function.

FC = Maximum number of stored indirect access files allowed.

CS = Total storage in PRU's allowed for all stored indirect access files. (One PRU is 64 words or 640 six-bit bytes.)

FS = Maximum size in PRU's allowed for individual stored indirect access files. (One PRU is 64 words or 640 six-bit bytes.)

AW = Access word. If the last digit is 4 or greater, the user is allowed to create direct access files.

NF = Number of local files allowed. This includes active APLUM files and coded files. Allow one extra file when saving or loading a workspace.

MS = Maximum number of mass storage PRU's allowed for local files, which includes active copies of indirect access files but not direct access files. (One PRU is 64 words or 640 six-bit bytes.)

SL = Maximum number of SRU's that can be expended during the job or session.

DS = Maximum file size in PRU's allowed for a direct access file (or workspace) at the time it is tied (or resaved). (One PRU is 64 words.) This limit is not imposed if the *RD* or *RM* option is used with *FTIE*.

AWSFIX and AFIFIX

The APL system uses the user control word associated with operating system permanent files to identify which files are APL workspaces and APL-structured files. When operating system commands are used to copy a workspace or APL-structured file or to transfer one to magnetic tape, the user control word is lost. An appropriate control word can be restored by use of the AWSFIX or AFIFIX utility program. The following example shows the procedure that would be used for a workspace:

```
BATCH     (Use the batch subsystem)
GET,AWSFIX/UN=APL0.
AWSFIX,name1,name2, ...
```

In the example, *name1*, *name2*, etc. represent names of permanent files stored under the current user number that should be processed. The procedure for restoring the user control word for an APL-structured file is identical except that AFIFIX is substituted for AWSFIX in the last two commands. Note that application of the wrong utility to a file may result in irreparable damage to the file.

The AWSFIX utility can also be used to "seal" a workspace. A workspace can be sealed to safeguard the privacy of its contents while still allowing the workspace to be used by others. Sealing a workspace provides the following protection:

1. An active copy of the workspace cannot be saved using *)SAVE* or *□SAVE*.
2. Objects cannot be copied from the workspace. However, the entire workspace can be loaded.
3. If the user of the workspace gains control (as a result of an error) an exit is taken from APL with the message 17: *PROTECTED WORKSPACE*.

These safeguards are intended for packages that start up by use of a latent expression (*□LX*). There is no procedure to unseal a workspace, so a separate unsealed copy of the workspace should be retained if future changes are contemplated. The following example shows the procedure that would be used to seal two stored workspaces named MATH and PHYSICS.

```
BATCH
GET,AWSFIX/UN=APL0.
AWSFIX,MATH=SEAL,PHYSICS=SEAL
```

Appendix A. Error Messages

APL ERROR MESSAGES

The following list describes the APL error messages and their meanings. It should be noted that most of these cause execution to halt (unless $\square TRAP$ is used to intercept the error processing), but function definition mode prints its error messages and then may continue processing.

00: *INTERRUPT*

This indicates that an interrupt has been received from a terminal or that the overstrike ⍁ has been entered as the first nonblank symbol for quote-quad input.

01: *IMPLICIT ERROR*

An implicit argument to a primitive function is not defined. The system variable $\square CT$ is required for the functions $A=B$, $A>B$, $A<B$, $A\geq B$, $A\leq B$, $A\neq B$, $A\in B$, $A\iota B$, $\boxplus B$, $A\boxplus B$, $A\mid B$, $\lceil B$, $\lfloor B$ and ιB. The variable $\square IO$ is required for indexing, the axis operator, $A\circledcirc B$, $A\iota B$, ιB, $\downarrow B$, $\uparrow B$, $?B$, and $A?B$. The variable $\square WSID$ must be defined for $\square SAVE$''. $\square RL$ is required for $A?B$ and $?B$, and $\square PP$ is required for monadic format. $\square ENV$ is required for $\square CR$, $\square EX$, $\square FX$, $\square NC$, $\square NL$, $\square STOP$, $\square TRACE$, $\square LOCK$, $\square LTIME$, $\square NAMES$ and $\square COPY$.

02: *SYNTAX ERROR*

Incorrectly formed statement. Check to be sure the statement has matched quotes, parentheses, and brackets. A common error is to forget to place an operation symbol between two variables when catenation is intended (e.g., $(M\ N)\rho Q$ instead of $(M,N)\rho Q$). Other causes include failure to provide a right argument to a function, and use of a branch arrow other than at the left end of a statement. Check the state indicator to be sure a local variable or label is not obscuring a function having the same name.

03: *DOMAIN ERROR*

The argument is not in the domain of the function or is an improper value for a system variable being specified. The following are examples of ways that domain errors can arise: ⍳3.5 (an integer is required), ⎕*IO*←14 (the index origin must be 1 or 0), ''+3 (character arguments are not allowed for many operations, even if the argument is empty), ⎕*PP*←45 (printing precision must be between 1 and 15). When ⎕*CT* is not defined, zero is used as ⎕*CT* in domain checks. Thus, ⍳1+1*E*¯14 would not be allowed because exact integers are required when ⎕*CT* is zero.

04: *LENGTH ERROR*

Lengths of the arguments to a function are incompatible, or the operation is not defined for arguments of that length.

05: *VALUE ERROR*

A variable used in an expression has not been assigned a value, a dyadic function has been used without a left argument, the result variable of a function that returns a result was not assigned a value, or a function was used for which there is no current definition. Check the state indicator to see if a local variable has obscured a global variable or function.

06: *RANK ERROR*

The ranks of the arguments are incompatible or the operation is not defined for an argument of that rank. For example: ⍳ 1 1 (not defined for vectors unless they have one element), *A*[1;2] (if *A* is a vector it has the wrong rank for the index applied), ⌹3 4 5⍴0 (not defined for ranks greater than 2).

07: *INDEX ERROR*

Index out of range. For example, if *A* is a three-element vector: *A*[4] in 1-origin, *A*[3] in zero origin, or *A*[0] in 1 origin. To find the current origin, display ⎕*IO*.

08: *LIMIT ERROR*

The operation exceeds limitations of the computer or the APL system. Limit errors can result from: attempts to generate a result greater in magnitude than about 1*E*322, attempts to execute a line longer than 150 characters (in a function, arguments to the execute function, or entered as input), or attempts to produce an array having a rank greater than 75.

09: *LOCKED OBJECT*

Attempt to specify a value for a locked variable (label or group). Locked variables can be redefined only by erasing them and then specifying them.

10: *WS FULL*

Insufficient space remains in the workspace for the operation. Use)*ERASE* to erase unneeded functions and variables to make more space available, or reset ⎕*WA* to allow a larger workspace. Some space can usually be reclaimed by executing a niladic branch (e.g., →). If more than one suspension is on the

state indicator, use a niladic branch for each suspension. The state indicator can also be cleared by use of 0 □*SAVE* '' (which also saves a copy of the workspace).

11: *WS NOT FOUND*
Although a file having that name was found, it was not recognizable as a workspace.

12: *DEFN ERROR*
Incorrect request in function definition mode. May result from providing header information other than the function name when reopening the function, use of a function name already in use for another global function or variable, or an illegal display or line editing request. Another cause is an attempt to close definition of a function having an incorrectly formed header or duplication of names used in the header or as labels.

13: *PHRASE NOT FOUND*
The phrase specified was not found in the line where it was sought. Be sure to specify the correct line number. Display the line to determine the correct phrase.

14: *SI DAMAGE*
Information on the state indicator has been lost due to changing a pendent function, by altering a function that is suspended more than once, or by changing the number or relative order of local variables in the header or label variables for a suspended function. This message is a warning--no corrective action is required. The pendent or suspended functions on the state indicator that are affected by *SI DAMAGE* are indicated by enclosing brackets. The affected functions cannot be continued, but they remain on the state indicator as long as other suspensions are above them. When the state indicator collapses to the affected suspension, the system automatically removes that suspension.

15: *NAME NOT FOUND*
No function or variable having that name exists.

16: *NAME IN USE*
A function or variable already has that name.

17: *PROTECTED WORKSPACE*
An attempt was made to save or copy from a sealed workspace, or an error in a sealed workspace was about to give control to the user.

18: *MIXED FUNCTION*
A mixed function has been used where a dyadic scalar function is required as an argument to an operator. For example: $A+.\iota B$, $A\circ.\iota B$, ϕ/B.

19: *UNDEFINED FUNCTION*
No such primitive function exists. For example: αB, $\neq B$ (no monadic $\neq$ function).

20: *operating system error message*

This message is a message from the operating system and usually concerns some sort of operation with a file or with a workspace. See the list of common errors under OPERATING SYSTEM ERROR MESSAGES below.

21: *FILE DAMAGE*

Usually indicates that one record of the file has been damaged. If an attempt to tie the file causes this message, the entire file may have been damaged. Most installations periodically copy all files to tape, and files can be restored to their condition when the last copy was made. Contact installation personnel for assistance. File damage may be reported erroneously when reading a direct access file in *RM* mode if repeated interference is encountered from another user writing the same record.

22: *WRONG TYPE FILE*

An attempt was made to use *CFREAD*, *CFPOS*, *CSUBMIT*, or *CFWRITE* on an APL-structured file, or an attempt was made to use *FREAD* or *FWRITE* on a coded file. Note that the operating system COPY commands do not preserve the type with a copy made from an APL-structured file. This error also results from an attempt to submit a direct access file using *CSUBMIT*.

23: *FILE TIE ERROR*

An attempt was made to use a file number or file name that was already in use, or an attempt was made to perform an operation (e.g., *FREAD*, *FWRITE*) that requires the file to be tied.

24: *CHANGE TO READ-ONLY FILE*

An attempt has been made to alter a file that was tied in *R* or *RM* mode.

OPERATING SYSTEM ERROR MESSAGES

The following list includes those operating system errors that the APL user is most likely to see. The timesharing manual or volume 1 of the operating system reference manual may provide further details and additional messages that are not included here, and may reflect recent changes.

20: *filename BUSY*

The specified direct access file is tied by another user in an incompatible mode. This may be caused by a system problem or telephone disconnect, in which case the file will be released in 10 minutes or can be accessed by using the operating system RECOVER command to resume the session that terminated abnormally. Occasionally a file will be left busy due to an operating system

error and will remain busy until a level zero deadstart (usually done at the start of the day). An APL-structured direct access file can usually be retrieved from this condition by using *RM* mode to make a new copy of the file.

20: *filename ALREADY PERMANENT*
A file having the indicated name already exists. This error may result if a workspace is being saved and a password, category, mode, file type (i.e., *IA* or *DA*), or a name different from □*WSID* was specified. This error can also occur when *FCREATE* attempts to create a direct access file having the same name as a file already in existence or when *FUNTIE* attempts to store a copy of an indirect access file that was created during the session. If the old file is no longer needed, use □*DROP* to eliminate it; otherwise, copy the new file to change its name.

20: *filename NOT FOUND*
The file does not exist under the specified user number, the user is not allowed to access the file, or the user did not provide a correct password for a file requiring a password.

20: *ILLEGAL USER ACCESS*
The user is either not allowed to create direct access files or is not allowed to create indirect access files.

20: *PF UTILITY ACTIVE*
The computer operations staff is using a permanent file utility program that prevents users from performing operations involving permanent files. Try the operation again.

20: *CATALOG OVERFLOW - SIZE*
The operation would cause the user's limit on total size of all indirect access files to be exceeded.

20: *CATALOG OVERFLOW - FILES*
The operation would exceed the limit on the number of files allowed for the account number.

20: *BAD FILE OR SUBMIT NOT ALLOWED*
This error results from use of *CSUBMIT* under the following circumstances: the user is not validated to use the SUBMIT facility, the file is not properly constructed, or the number of jobs allowed for the user would be exceeded.

20: *PARITY ERROR*
20: *ADDRESS ERROR*
20: *DEVICE STATUS ERR.*
20: 6681 *FUNCTION REJ.*
20: *DEVICE RESERVED*
20: *DEVICE NOT READY*
Any of these messages indicates a malfunction in the computer or a storage device. Try the operation again, and if the problem persists, notify installation personnel.

20: *TRACK LIMIT*

There is no space available on the device where the file resides. Be sure you have not accidentally created a gigantic file. If you use very large files, you may need to make special arrangements with the installation personnel.

20: *FILE TOO LONG*

The indirect access file or workspace cannot be saved because it would exceed the user's size limit for indirect access files, or the direct access file being tied or the direct access stored workspace being re-saved presently occupies more space than the user's size limit for direct access files.

ABNORMAL EXITS FROM APL

PARAMETER ERROR

This error indicates the APL command was incorrect in form or that a parameter was specified incorrectly.

TIME LIMIT

A *TIME LIMIT* occurred and the T,*number* command was not used to continue processing (see Section 13).

SRU LIMIT

An *SRU LIMIT* error occurred and the S,*number* command was not used to continue processing (see Section 13).

PP ABORT

A peripheral processing unit requested that the program be terminated.

OPERATOR DROP

The computer operator intervened and terminated the program.

FILE LIMIT

More active files were used than are allowed by the user's validation limits.

SYSTEM ABORT
SUBSYSTEM ABORT
OVERIDE CONDITION
PARITY ERROR
FORCED ERROR

Any of these indicates a computer or operating system malfunction. Contact the system analyst.

APL SYSTEM ERROR (or *EXCHANGE PACKAGE*)

This indicates a defect in the APL system or a computer or operating system malfunction. Please report this error to installation personnel along with work that led to the problem and any further output from the APL system. Unlike most error messages, this is not an indication of an error by the APL programmer.

OTHER MESSAGES

DEL
This indicates that the input line was cancelled.

OVL
This indicates that the preceding input line was too long for the operating system.

TIME LIMIT
This indicates that the user reached a limit on allowed consumption of computer resources. See the T,*number* command in Section 13.

SRU LIMIT
This indicates that the user reached a limit on allowed consumption of System Resource Units (SRUs). See the S,*number* command in Section 13.

Appendix B. Output Format

Character output is sent to a terminal unaltered except for character translation required for the particular type of terminal and omission of trailing blanks in rows of a matrix. This omission of trailing blanks in character output speeds the printing of the result from □*CR*, the printing of tables of names, and so forth.

Numeric output is ordinarily shown in decimal form unless decimal form would not be sufficiently compact. When decimal form is used, up to □*PP* significant digits are shown, but trailing zeros beyond the decimal point are omitted, as is the decimal point itself if no digits follow. Numbers with a magnitude less than 1 are shown with a zero before the decimal point (e.g., 0.025, 0.125). All numbers in a column have their decimal points aligned.

Exponential form is used if decimal form would require more than 3 zeros after the decimal point before the first significant digit, if aligning decimal points in the column would require more than 1.5×□*PP* character positions, or if more than □*PP* digits would appear to the left of the decimal point. If any number in a column requires exponential format, the entire column is shown in exponential format with the decimal points and exponents aligned. All numbers in the column are shown with the same number of digits in the mantissa. The number of mantissa digits is less than □*PP* according to how many trailing zeros would otherwise appear in all numbers in the column. If no numbers in the column have digits beyond the decimal point, the decimal point is omitted.

Numbers in adjacent columns are separated by at least one space. However, no more spaces than necessary are used.

Appendix C. Character Sets and Terminals

This section discusses character sets and terminal types from the point of view of installations using NAM/IAF (Network Access Method/Interactive Facility) for communication with terminals. Appendix F contains further information and exceptions that apply to terminals at installations that do not use NAM/IAF.

Many different types of terminals can be used with the APL system. In addition, card readers, printers, and files can be used for input and output. The characters available on these various devices are shown in Table C-2. Many of these devices cannot print the full set of APL characters. APL characters are translated so as to print the same whenever possible. When no related symbol is available, the symbol is represented as a dollar sign followed by two mnemonic symbols (e.g., $IO for ⍳ and $RO for ⍴). For input, if the symbols following the dollar sign are not recognized as one of these mnemonics, the dollar sign is entered as a dollar sign. In Table C-2 where two characters appear in the same column, either character may be used for input, but all output uses the second character. Note that the APL system assumes the same terminal type for input and output. Where there is a blank entry in the table, the "bad character symbol," ⎕AV[220], is used. Note that the ⎕AV indices are for 0-origin. The column for APL coded files includes the octal (base 8) values used. The print symbols shown for coded files assume an ASCII printer will be used; a few symbols print differently on other printers. Note that future versions of the APL 2 system may be changed to preserve exact equivalents for all ASCII characters. This would affect the TT=BATCH, TT=713, and coded file translations.

LOG ON CHARACTERS AND TERMINAL CONTROLS

Most terminals used with computers can be classified as either ASCII terminals or Selectric terminals. (Selectric terminals are distinguished from ASCII terminals in that Selectric terminals are based on an IBM Selectric print mechanism, although the terminals themselves are produced by several manufacturers.) In addition, the terminal may or may not be equipped to print the APL character set. Some terminals can easily be switched from the APL character set (e.g. *L* and □ are the lower and upper case symbols on the L key) to a "standard" character set (e.g. l and L are the two symbols on the L key). In some cases you select the character set by changing a switch setting, while in other cases you select the character set by replacing the type element. In either situation, the signal sent to the computer when a given key is pressed does not change when you switch character sets -- only the printed symbol changes. It is therefore important that the computer be notified of the character set you are using.

In a normal NAM/IAF log on, you first press RETURN (which NAM/IAF uses to determine the data rate of the terminal), then you send) RETURN. The right parenthesis is used to determine the type of terminal (ASCII or Selectric), whether APL is available on the terminal, and what keyboard arrangement or transmission codes are used (bit pairing, typewriter pairing, Correspondence, or EBCDIC). If the APL character set is available, select the APL character set before sending the right parenthesis so that the code for the APL right parenthesis will be sent.

The TT= option on the APL command should be used if the terminal does not have the APL character set. In addition, for APL Selectric terminals, *TT=COR* may be used if overstrikes are desired for the symbols {}$ ◇ ⊢ ⊣. For most non-APL terminals the TT=713 option is recommended.

Note that visual fidelity is not preserved for non-APL terminals. Non-APL terminals are not recommended for program development, although they may be satisfactory for entering data or transactions.

Table C-1 shows the appropriate TT= option for each terminal type, as well as the terminal controls normally used to cancel lines, correct input, or interrupt a program. In this table, a circle around a letter means the CTRL key should be held down while typing the letter. For example, Ⓧ means CTRL X.

TABLE C-1. Terminal Controls and Options.

	ASCII with APL print	ASCII	Selectric with APL print	Selectric
TT= option	none	TT=713	TT=COR (optional)	TT=713
Cancel line	(X) RETURN	(X) RETURN	BACKSPACE to begin of line, ATTN	BACKSPACE to begin of line, ATTN
Correct line	BACKSPACEs LINE FEED	BACKSPACEs (or (H)) LINE FEED	BACKSPACEs ATTN	BACKSPACEs ATTN
Interrupt while executing	(P) RETURN	(P) RETURN	ATTN:RETURN	ATTN:RETURN
Stop □ input	→	$GO	→	$GO
Stop ⍞ input	⎕	$G.	⎕	$G.

Most of the NAM/IAF controls shown in Table C-1 are system default controls; they are the same as you would usually use with another language. In addition, the APL system requests special editing mode (which allows APL to use overstrikes, partial line correction with a caret prompt, and the full character set), and selects a NAM/IAF printing width of 0 (which prevents NAM/IAF from dividing lines of input and output according to the printing width of the terminal). These special selections made by the APL system are equivalent to the effect of the following NAM/IAF commands typed at a terminal:

```
ESC SE=Y RETURN  (To request special editing.)
ESC PW=0 RETURN  (For no print width processing.)
```

These commands to NAM/IAF are recognized only if they occur at the beginning of a keyboard entry. Spaces are shown above for the sake of clarity, but no spaces should actually be entered. When the APL session ends, APL requests no special editing. This is equivalent to the following request from a terminal:

```
ESC SE=N RETURN
```

However, NAM/IAF printing width remains 0. To reset the printing width, type a command like the following:

```
ESC PW=132 RETURN (To set the width to 132.)
```

These examples, as well as Table C-1, are based on the default NAM/IAF terminal controls. However, NAM/IAF allows you to designate other characters to be used in place of the special control characters.* Substitutions might be desirable when using a special device on which the default controls are not available or are reserved for a special purpose. Further details can be found in manuals describing NAM/IAF.

SPECIFYING NAM/IAF CHARACTER SET

During the normal log on procedure with the computer connection through telephone lines, the first characters from the terminal allow the system to detect the data rate and character set in use. When the terminal is directly wired to the computer the data rate and character set may be predetermined. If you wish to change the character set of the terminal (e.g., to use another language) you should identify the new character set to the system as follows:

ESC CD=A RETURN (Typed using the old character set.)

The system responds with two line feeds. You should then switch to the new character set and type:

)RETURN

SPECIAL CHARACTERS

The character formed by overstriking *C* and *R* causes a carrier return (without a line feed) on an ASCII terminal. For Selectric terminals, no exact equivalent exists, so a carrier return with line feed occurs. The symbol formed by overstriking *U* and *S* results in a carrier return and line feed for all terminal types. (For output to coded files, *U* over *S* also causes a new line.) The line feed itself is also available and is represented by overstriking *L* and *F*.

Note that earlier versions of the APL system used the *CR* overstrike to mean carrier return with line feed. The symbol formerly entered as *C* over *R* is now printed as *U* over *S*, regardless of whether it was in a program or data. The *CR* overstrike remains at ⎕*AV*[13] (in 0 origin) as a result of rearrangement of ⎕*AV*. However, the effect of ⎕*AV*[13] has changed for some terminal types and for output to coded files.

STANDARD SWITCH SETTINGS

The following information is intended as a general discussion on choosing switch settings for terminals. Because of the many variations between terminals and the various conventions adopted by installations, these suggestions can only serve as a

*The cancel line character should not be changed, because APL will only recognize ⊗ for cancel line.

general guide. Further information can be obtained from personnel at the computer installation or from the instruction manual provided by the manufacturer of the terminal.

LINE/LOCAL switch. LOCAL mode prevents signals from being sent to the computer. The LINE position should be used.

CAPS LOCK. This key on ASCII terminals causes the codes for upper case letters to be sent even if the shift key is not used. This option should not be used for APL terminals.

DATA RATE. Standard rates usually available are 110 BAUD (10 cps) and 300 BAUD (30 cps) for ASCII terminals and 135 BAUD for Selectric terminals. Much higher data rates are sometimes available.

Character set. Some terminals have a switch to select the character set. The APL setting may be marked APL or ALT CHAR SET. On some terminals resetting the character set key has no immediate effect unless the character set lock key is also depressed.

Parity. Even parity is standard at most installations.

FDX/HDX. In full duplex mode (FDX), characters sent by the terminal are echoed back by the communications processer. The terminal prints the character as a result of receiving it from the system. This mode helps you to determine whether the transmission was received correctly. In half duplex mode, the terminal always prints the characters as the keys are pressed, and the system does not echo the characters as they are received. The terminal and system must both use the same mode or else characters will be printed twice (or will be garbled), or they will not print at all. You should determine (possibly by experimentation) the standard mode (usually HDX) for the installation. (If the acoustic coupler has a similar switch, use the full duplex selection, regardless of the convention between the terminal and the system.)

Table C-2. APL Character Set.

⎕AV Index	APL Symbol (Overstrike)	ASCII Symbol (Name)	TT=713 Symbol	BATCH Printer	B501 Printer	APL Coded Files
0	N (NU)	(NUL)	$NU	$NU	$NU	
1	H (SH)	(SOH)	$SH	$SH	$SH	
2	S (ST)	(STX)	$ST	$ST	$ST	
3	E (ET)	(ETX)	$ET	$ET	$ET	
4	O (EO)	(EOT)	$EO	$EO	$EO	
5	N (EN)	(ENQ)	$EN	$EN	$EN	
6	K (AK)	(ACK)	$AK	$AK	$AK	
7	B (BL)	(BEL)	$BL	$BL	$BL	
8	B (BJ)	(BS)	$BJ	$BJ	$BJ	
9	H (HT)	(HT)	$HT	$HT	$HT	
10	E (LF)	(LF)	$LF	$LF	$LF	
11	V (VT)	(VT)	$VT	$VT	$VT	
12	F (FD)	(FF)	$FD	$FD	$FD	
13	R (CR)	(CR)	$CR	$CR	$CR	
14	O (SO)	(SO)	$SO	$SO	$SO	
15	S (SI)	(SI)	$SI	$SI	$SI	
16	D (DE)	(DLE)	$DE	$DE	$DE	
17	D (D1)	(DC1)	$D1	$D1	$D1	
18	D (D2)	(DC2)	$D2	$D2	$D2	
19	D (D3)	(DC3)	$D3	$D3	$D3	
20	D (D4)	(DC4)	$D4	$D4	$D4	
21	N (NK)	(NAK)	$NK	$NK	$NK	
22	S (SY)	(SYN)	$SY	$SY	$SY	
23	B (EB)	(ETB)	$EB	$EB	$EB	
24	C (CA)	(CAN)	$CA	$CA	$CA	
25	M (EM)	(EM)	$EM	$EM	$EM	
26	S (SB)	(SUB)	$SB	$SB	$SB	
27	S (ES)	(ESC)	$ES	$ES	$ES	
28	F (FS)	(FS)	$FS	$FS	$FS	
29	G (GS)	(GS)	$GS	$GS	$GS	
30	R (RS)	(RS)	$RS	$RS	$RS	
31	U (US)	(US)	$US	$US	$US	
32	blank	blank	blank	blank	blank	blank (55B)
33	! (' .)	!	$EX !	$EX !	$EX	! (66B)
* 34	" (¨ ')	"	$DQ	$DQ	$DQ	
* 35	≠ (+=)	#	$PD	$PD	$PD	
36	$ (S |)	$	$	$	$	$ (53B)
* 37	/ (/ :)	%	$PR	$PR	$PR	
* 38	& (8 \)	&	$AM	$AM	$AM	
39	'	'	$QT '	$QT '	$QT	' (70B)
40	(	(	(	(	(	((51B)
41	)	)	)	)	)	) (52B)
42	*	*	*	*	*	* (47B)
43	+	+	+	+	+	+ (45B)
44	,	,	,	,	,	, (56B)
45	-	-	-	-	-	- (46B)

Table C-2. APL Character Set, Continued.

□AV Index	APL Symbol (Overstrike)	ASCII Symbol (Name)	TT=713 Symbol	BATCH Printer	B501 Printer	APL Coded Files
46	.	.	.	.	.	.(57B)
47	/	/	/	/	/	/(50B)
48	0	0	0	0	0	0(33B)
49	1	1	1	1	1	1(34B)
50	2	2	2	2	2	2(35B)
51	3	3	3	3	3	3(36B)
52	4	4	4	4	4	4(37B)
53	5	5	5	5	5	5(40B)
54	6	6	6	6	6	6(41B)
55	7	7	7	7	7	7(42B)
56	8	8	8	8	8	8(43B)
57	9	9	9	9	9	9(44B)
58	:	:	$CL :	$CL :	$CL :	:(00B)
59	;	;	$SC ;	$SC ;	$SC ;	;(77B)
60	<	<	$LT <	$LT <	$LT <	<(72B)
61	=	=	$EQ =	$EQ =	$EQ =	=(54B)
62	>	>	$GT >	$GT >	$GT >	>(73B)
63	?	?	$QU ?	$QU ?	$QU ?	?(71B)
* 64	@ (C∘)	@	$AT	$AT	$AT	
65	A	A	A	A	A	A(01B)
66	B	B	B	B	B	B(02B)
67	C	C	C	C	C	C(03B)
68	D	D	D	D	D	D(04B)
69	E	E	E	E	E	E(05B)
70	F	F	F	F	F	F(06B)
71	G	G	G	G	G	G(07B)
72	H	H	H	H	H	H(10B)
73	I	I	I	I	I	I(11B)
74	J	J	J	J	J	J(12B)
75	K	K	K	K	K	K(13B)
76	L	L	L	L	L	L(14B)
77	M	M	M	M	M	M(15B)
78	N	N	N	N	N	N(16B)
79	O	O	O	O	O	O(17B)
80	P	P	P	P	P	P(20B)
81	Q	Q	Q	Q	Q	Q(21B)
82	R	R	R	R	R	R(22B)
83	S	S	S	S	S	S(23B)
84	T	T	T	T	T	T(24B)
85	U	U	U	U	U	U(25B)
86	V	V	V	V	V	V(26B)
87	W	W	W	W	W	W(27B)
88	X	X	X	X	X	X(30B)
89	Y	Y	Y	Y	Y	Y(31B)
90	Z	Z	Z	Z	Z	Z(32B)

Table C-2. APL Character Set, Continued.

□AV Index	APL Symbol (Overstrike)	ASCII Symbol (Name)	TT=713 Symbol	BATCH Printer	B501 Printer	APL Coded Files
91	[	[	$OB [	$OB [	$OB [	[(61B)
92	\	\	$BS \	$BS	$BS	\(75B)
93	]	]	$CB]	$CB]	$CB]	](62B)
* 94	¨ (¨-)	^	$CX	$CX	$CX	
* 95		_	$UL	$UL _	$UL _	_(65B)
* 96	¯ ('-)	`	$AC	$AC	$AC	
97	A (A_)	a	$AA	$AA	$AA	A(01B)
98	B (B_)	b	$BB	$BB	$BB	B(02B)
99	C (C_)	c	$CC	$CC	$CC	C(03B)
100	D (D_)	d	$DD	$DD	$DD	D(04B)
101	E (E_)	e	$EE	$EE	$EE	E(05B)
102	F (F_)	f	$FF	$FF	$FF	F(06B)
103	G (G_)	g	$GG	$GG	$GG	G(07B)
104	H (H_)	h	$HH	$HH	$HH	H(10B)
105	I (I_)	i	$II	$II	$II	I(11B)
106	J (J_)	j	$JJ	$JJ	$JJ	J(12B)
107	K (K_)	k	$KK	$KK	$KK	K(13B)
108	L (L_)	l	$LL	$LL	$LL	L(14B)
109	M (M_)	m	$MM	$MM	$MM	M(15B)
110	N (N_)	n	$NN	$NN	$NN	N(16B)
111	O (O_)	o	$OO	$OO	$OO	O(17B)
112	P (P_)	p	$PP	$PP	$PP	P(20B)
113	Q (Q_)	q	$QQ	$QQ	$QQ	Q(21B)
114	R (R_)	r	$RR	$RR	$RR	R(22B)
115	S (S_)	s	$SS	$SS	$SS	S(23B)
116	T (T_)	t	$TT	$TT	$TT	T(24B)
117	U (U_)	u	$UU	$UU	$UU	U(25B)
118	V (V_)	v	$VV	$VV	$VV	V(26B)
119	W (W_)	w	$WW	$WW	$WW	W(27B)
120	X (X_)	x	$XX	$XX	$XX	X(30B)
121	Y (Y_)	y	$YY	$YY	$YY	Y(31B)
122	Z (Z_)	z	$ZZ	$ZZ	$ZZ	Z(32B)
* 123	{ ([∘)	{	$LB	$LB	$LB	
124	⌷	¦	$MD	$MD	$MD	
* 125	} (]∘)	}	$RB	$RB	$RB	
* 126	~	^	$TL	$TL ^	$TL ^	^(76B)
127	⍬ (DZ)	(DEL)	$DZ	$DZ	$DZ	
128		(K0)				
129		(K1)				
130		(K2)				
131		(K3)				
132		(K4)				
133		(K5)				
134		(K6)				
135		(K7)				

Table C-2. APL Character Set, Continued.

□AV Index	APL Symbol (Overstrike)	ASCII Symbol (Name)	TT=713 Symbol	BATCH Printer	B501 Printer	APL Coded Files
136		(K8)				
137		(K9)				
138		(K10)				
139		(K11)				
140		(K12)				
141		(K13)				
142		(K14)				
143		(K15)				
144		(K16)				
145		(K17)				
146		(K18)				
147		(K19)				
148		(K20)				
149		(K21)				
150		(K22)				
151		(K23)				
152		(K24)				
153		(K25)				
154		(K26)				
155		(K27)				
156		(K28)				
157		(K29)				
158		(K30)				
159		(K31)				
160	∧	(N0)	$AN	$AN	$AN ∧	
161	∨	(N1)	$OR	$OR	$OR ∨	
162	⍲ (∧~)	(N2)	$ND	$ND	$ND	
163	⍱ (∨~)	(N3)	$NR	$NR	$NR	
164	≤	(N4)	$LE	$LE	$LE ≤	
165	≠	(N5)	$NE	$NE	$NE ≠	
166	≥	(N6)	$GE	$GE	$GE ≥	
167	⍋ (Δ|)	(N7)	$UG	$UG	$UG	
168	⍒	(N8)	$DG	$DG	$DG	
** 169	↑	(N9)	$TA	$TA	$TA ↑	
170	↓	(N10)	$DR	$DR	$DR ↓	
** 171	←	(N11)	$IS	$IS	$IS	
172	→	(N12)	$GO	$GO	$GO →	
173	⍝ (∩∘)	(N13)	$LP	$LP	$LP	
174	⍫ (∇~)	(N14)	$LD	$LD	$LD	
175	∇	(N15)	$DL	$DL	$DL	
176	⌊	(N16)	$MN	$MN		
177	⌈	(N17)	$MX	$MX		
** 178	×	(N18)	$ML	$ML	$ML	&(67B)
** 179	÷	(N19)	$DV	$DV	$DV	%(63B)
** 180	⍠	(N20)	$DI	$DI	$DI	"(64B)

Table C-2. APL Character Set, Continued.

	⎕AV Index	APL Symbol (Overstrike)	ASCII Symbol (Name)	TT=713 Symbol	BATCH Printer	B501 Printer	APL Coded Files
**	181	-	(N21)	$NG	$NG	$NG	#(60B)
	182	Δ	(N22)	$DT	$DT	$DT	
	183	⊣ (←|)	(N23)	$RK	$RK	$RK	
	184	⊢ (→|)	(N24)	$LK	$LK	$LK	
	185	○	(N25)	$CI	$CI	$CI	
**	186	⊛ (○*)	(N26)	$LG	$LG	$LG	@(74B)
	187	⊖ (○-)	(N27)	$RU	$RU	$RU	
	188	⌽ (○|)	(N28)	$RT	$RT	$RT	
	189	⍉ (○\)	(N29)	$TP	$TP	$TP	
	190	◇ (∧∨)	(N30)	$DM	$DM	$DM	
	191	⍙ (Δ_)	(N31)	$DU	$DU	$DU	
	192	⍳	(N32)	$IO	$IO	$IO	
	193	⍴	(N33)	$RO	$RO	$RO	
	194	⊥	(N34)	$BV	$BV	$BV	
	195	⊤	(N35)	$RP	$RP	$RP	
	196	⌶ (⊥⊤)	(N36)	$IB	$IB	$IB	
	197	⊂	(N37)	$ID	$ID	$ID	
	198	⊃	(N38)	$IN	$IN	$IN	
	199	∩	(N39)	$IX	$IX	$IX	
	200	∪	(N40)	$UN	$UN	$UN	
	201	∘	(N41)	$NL	$NL	$NL	
	202	⎕	(N42)	$QD	$QD	$QD	
	203	⍞ (⎕')	(N43)	$QP	$QP	$QP	
	204	⍀ (\-)	(N44)	$BT	$BT	$BT	
	205	⌿ (/-)	(N45)	$SM	$SM	$SM	
	206		(N46)				
	207	⍁ (⎕÷)	(N47)	$XD	$XD	$XD	
	208	⍵	(N48)	$OM	$OM	$OM	
	209	⍺	(N49)	$AL	$AL	$AL	
	210		(N50)				
	211		(N51)				
	212		(N52)				
	213	∈	(N53)	$EP	$EP	$EP	
	214	⍎ (⊥∘)	(N54)	$EV	$EV	$EV	
	215	⍕ (⊤∘)	(N55)	$FM	$FM	$FM	
	216	⍪ (-,)	(N56)	$CN	$CN	$CN	
	217		(N57)				
	218		(N58)				
	219		(N59)				
	220	⍒ (∇Δ)	(N60)	$BC	$BC	$BC	
	221		(N61)				
	222		(N62)				
	223		(N63)				
	224	⍓ (*OUT*)	(G0)	$G.	$G>	$G>	
	225	⍠ (*OU*)	(G1)	$OU	$OU	$OU	

Table C-2. APL Character Set, Continued.

□AV Index	APL Symbol (Overstrike)	ASCII Symbol (Name)	TT=713 Symbol	BATCH Printer	B501 Printer	APL Coded Files
226		(G2)				
227		(G3)				
228		(G4)				
229		(G5)				
230		(G6)				
231		(G7)				
232		(G8)				
233		(G9)				
234		(G10)				
235		(G11)				
236		(G12)				
237		(G13)				
238		(G14)				
239		(G15)				
240		(G16)				
241		(G17)				
242		(G18)				
243		(G19)				
244		(G20)				
245		(G21)				
246		(G22)				
247		(G23)				
248		(G24)				
249		(G25)				
250		(G26)				
251		(G27)				
252		(G28)				
253		(G29)				
254		(G30)				
255		(E0)				

* Future versions of APL may change the APL coded file conversions to use the ASCII graphic symbol to represent the ASCII character.

** Future versions of APL may change the APL coded file conversions to allow only the $ mnemonic to enter or print these characters.

Appendix D. APL Control Card

The optional parameters on the APL timesharing command (or batch control card) allow specification of the type of terminal (or batch options) to be used, the workspace to be used (thus avoiding a subsequent *LOAD* command), and the constraints on the field length to be used. The general form for the control card is:

APL,*option*,*option*,*option*, ...

where an *option* is of the form *keyword* or *keyword=value*.

Indicating terminal type. When no terminal type is specified, APL assumes TT=ASCAPL as the terminal type if the job was entered from timesharing. (This default may be changed by the installation.) If the job is a batch or remote batch job, APL assumes the TT=BATCH option. See Appendix C or Appendix F for specific recommendations. Other terminal types can be specified as follows:

TT=COR — Correspondence Selectric APL terminal (□*TT*=1). This option assumes the communications system recognizes the terminal as an APL terminal.

TT=TYPE — Typewriter-paired APL terminals (□*TT*=2). This is applicable only if the communications system does not recognize the terminal as an APL terminal.

TT=BIT — Bit-paired APL terminal (□*TT*=3). This is applicable only if the communications system does not recognize the terminal as an APL terminal.

TT=ASCAPL — This type (□*TT*=4) is appropriate when the communications system translates APL terminal codes into a standard intermediate code.

TT=TTY33 For Teletype 33 terminal or similar devices (□*TT*=5). TT=713 is recommended instead for most other ASCII terminals.

TT=ASCII For full ASCII terminals not equipped to print the APL character set (□*TT*=6). This may also be used for non-APL correspondence terminals, but TT=713 is recommended instead.

TT=BATCH For devices that support the ASCII 64-character set (□*TT*=7). Usually used for batch or remote batch ASCII printers.

TT=B501 For batch 501 printer (□*TT*=8).

TT=TTY383 For certain Teletype 38 models (□*TT*=9). See Appendix F.

TT=713 For full ASCII terminals or correspondence terminals not having the APL character set. Avoids frequent use of shift key for letters. E.g. either T or t may be entered for the APL letter *T*.

Indicating batch output options. The following options are intended primarily for batch users of APL. If the APL control card does not specify output options, it is assumed that timesharing users do not wish these options and that batch users do want them.

LO=EPB Any or all of the options E, P, or B may be specified. Any options not specified are not used.

E Echo input. The APL lines read as input are also sent as output.

P Prohibit prompt. The normal APL input prompts (6 spaces or □: plus transparent mode control bytes, a lack of which may cause the input translation for terminals to be incorrect) are not sent to the output file.

B Blank in first column. Causes a blank to be added to the front of each output line to prevent the first character from being used for printer carriage control.

LO=0 To select none of the E, P, or B options.

Input and output file specification. The input and output files normally used for APL are named INPUT and OUTPUT. For timesharing jobs this causes input to come from the terminal and output to be sent to the terminal. For batch jobs input

ordinarily is from the card deck or *CSUBMIT* file, and output is to a line printer. Other operating system files can be used instead. APL translation of input and output is according to the TT= option (or the default which depends on whether the job is batch type or timesharing type).

I=*file-name* Causes input to be read from the named file.

L=*file-name* Causes output to go to the named file.

L=0 No APL output is produced. (All output is discarded.)

Initial workspace specification. If no workspace is specified, a clear workspace is used. Some effort can be saved by specifying the initial workspace name on the APL control card.

WS=*wsname* APL operations begin with a copy of the named workspace as the active workspace.

UN=*user-number* Used to specify the user number of the initial workspace. Required only if the user number of the workspace differs from that used when signing on.

PW=*passwd* If the workspace belongs to another user and has a password, the password must be provided in order to use it.

Field length specification. The field length used by APL includes the central memory used for the APL system and the active workspace. The user is not allowed to specify a field length greater than that permitted by validation limits associated with the user name, or greater than the limit imposed by the computer operator. If no field length is specified, the APL system chooses a minimum field length that depends on the current version of APL, and a maximum field length of 24576 words (60000 octal) or the maximum allowed, whichever is less. The field length is used for the APL system and the active workspace. The actual field length used varies dynamically. If storage requirements exceed the maximum field length, a *WS FULL* message results.

MX=*number* Sets the maximum field length. The number is assumed to be in decimal form unless followed immediately by B, in which case it is interpreted as octal. The value is actually rounded up to a multiple of 64.

MN=*number* Sets the minimum field length. The number is assumed to be in decimal form unless followed immediately by B, in which case it is interpreted as octal. The value is actually rounded up to a multiple of 64.

Suppressing banner. The *NH* keyword (for no heading) may be used on the APL control card to prevent the APL system from printing the usual banner (APL system identification) at the beginning of the APL session.

Appendix E. Numerical Limits and Precision

The CYBER computers can represent nonzero numbers having magnitudes in the approximate range 1.27*E*322 to 3.14*E*⁻294. An operation that would ordinarily produce a number smaller in magnitude than 3.14*E*⁻294 actually produces zero. Operations that would produce results of magnitude greater than 1.27*E*322 produce a *DOMAIN ERROR*.

Numbers within this magnitude range are represented with an accuracy of about 14 decimal digits (more precisely, to within 1 part in 2*48). The simple operations such as addition, subtraction, multiplication, and division can be expected to be accurate to within 1 part in 2*48 except when cancellation magnifies the errors. However, operations involving numbers that are integers or powers of 2 give exact results unless the magnitudes differ greatly. For example, exact results are given by: .5+4, .25-.125, 8-3.

Appendix F. Use of Terminals at Installations without NAM/IAF

When NAM/IAF is not used for communications with terminals, the log on procedure is somewhat more complicated, and the user must know more about the type of terminal in use. Also, the system does not sense the character rate of the terminal, although it determines some information about the terminal class from the first characters sent. Furthermore, operating system messages printed on the terminal may use the wrong character set. For example, *TIME LIMIT* may be printed as ≠~⍳|∈ □⍳]⍳~≠ -- instead of letters the upper case symbols on the same keys as the letters are printed.

TERMINAL TYPES

ASCII terminals that have the APL character set are divided into three classes according to which ASCII signals are associated with the APL symbols. The most common type is typewriter paired; these terminals have the APL symbol for multiplication on the same key as the ASCII symbol for equals. The second class, bit-paired terminals, have the APL symbol for subtraction on the same key as the ASCII symbol for equals. The third class, TTY383, applies to Teletype 38 terminals with the following model numbers: 3841/4EA, 3841/4EG, 3851/6JA, and 3851/6JG.

ASCII terminals without the APL character set either have the full ASCII character set (e.g. both capital and small letters) or only the partial character set (e.g. no small letters). In either case, the terminal type TT=713 is recommended. This translation treats either the capital or small letters as the APL letters *A* to *Z* and avoids frequent use of the shift key. (The TTY33 terminal type is nearly obsolete; the 713 type is preferable for most terminals other than Teletype 33 terminals. The ASCII translation allows small letters to be distinguished from capital letters, but this capability is usually a nuisance since small ASCII letters become underlined APL letters.)

Selectric APL terminals use either correspondence transmission codes or EBCDIC transmission codes. The EBCDIC codes are not ordinarily supported. Correspondence terminals that do not print the APL character set can be used with the TT=713 terminal type as if they were ASCII terminals.

LOG-ON PROCEDURE

The log-on procedure is summarized in Table F-1 for the various types of terminals. The first step is to establish a telephone connection with the computer, as discussed in Section 1. However, when NAM/IAF with auto baud detect is not used, the telephone number may vary according to the type of terminal and the data rate to be used.

Table F-1. Log-on Procedure

Terminal Type	First transmission	Change character set	TT= option	Symbol for = when not in APL
ASCII typewriter-paired APL	*A* RETURN	TERM,TTY	TYPE	×
ASCII bit-paired APL	*A* RETURN	TERM,TTY	BIT	-
ASCII TTY383 APL	*A* RETURN	TERM,TTY	TTY383	-
Correspondence APL	*A* ATTN		COR	=
ASCII non-APL	RETURN		713	=
Correspondence non-APL	RETURN		713	=

The initial transmission from the terminal indicates whether the terminal has the APL character set. Enter the characters shown in Table F-1. Then provide the account family, account number, and password as discussed in Section 1.

When the system prints

RECOVER/SYSTEM:

reply with TERM,TTY if Table F-1 indicates this command is required for your terminal type. Then type the APL command with the appropriate terminal type option from Table F-1. For example,

APL,TT=COR

would be used to indicate that a correspondence APL terminal is in use. For some terminal types, you must use the × symbol or - symbol in place of = because the operating system assumes that the ASCII symbols are in use. The last column in the table shows the character to use instead of = for the APL command and other operating system commands. Note that these substitutions must be made for commands discussed in Section 13.

TERMINAL CONTROLS

Table F-2 shows the terminal controls used to cancel an input line, stop a program while executing, and to stop a program while requesting input. The two entries for halting a program requesting input are for □ input and ⍞ input, respectively. The procedure to cancel an entire input line for correspondence terminals requires that the type element be positioned beyond what was already typed. When you correct input according to the procedure in Table F-2, the system responds by printing a caret under the first character to be replaced. You then type replacement characters. For ASCII terminals you can also use the LINE FEED key instead of BREAK; this procedure does not print the caret prompt, but you do not need to wait for the system to respond before providing replacement characters.

Table F-2. Terminal Controls

Terminal type	Cancel input	Correct input	Stop program	Stop input
ASCII with APL print	BREAK	BACKSPACEs LINE FEED	BREAK	⎕ or →
Non-APL ASCII	BREAK	BACKSPACEs (or CTRL H) LINE FEED	BREAK	$G. or $GO
APL Correspondence	ATTN	BACKSPACEs ATTN	ATTN	⎕ or →
Non-APL Correspondence	ATTN	BACKSPACEs ATTN	ATTN	$G. or $GO

INDEX

COMMENT SHEET

MANUAL TITLE: CDC APL Version 2 Reference Manual

PUBLICATION NO.: 60454000 **REVISION:** F

NAME: _____

COMPANY: _____

STREET ADDRESS: _____

CITY: _____ **STATE:** _____ **ZIP CODE:** _____

This form is not intended to be used as an order blank. Control Data Corporation welcomes your evaluation of this manual. Please indicate any errors, suggested additions or deletions, or general comments below (please include page number references).

☐ Please reply ☐ No reply necessary

CUT ALONG LINE

AA3419 REV. 4/79 PRINTED IN U.S.A.

NO POSTAGE STAMP NECESSARY IF MAILED IN U.S.A.

FOLD ON DOTTED LINES AND TAPE

TAPE

TAPE

FOLD

FOLD

NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

BUSINESS REPLY MAIL

FIRST CLASS PERMIT NO. 8241 MINNEAPOLIS, MINN.

POSTAGE WILL BE PAID BY

CONTROL DATA CORPORATION

Publications and Graphics Division
215 Moffett Park Drive
Sunnyvale, California 94086

CUT ALONG LINE

FOLD

FOLD

TAPE

TAPE

TABLE OF DISTINGUISHED FUNCTIONS AND VARIABLES

DISTINGUISED VARIABLES

DISTINGUISHED FUNCTIONS

TABLE OF FILE SYSTEM FUNCTIONS

CORPORATE HEADQUARTERS, P.O. BOX 0, MINNEAPOLIS, MINN. 55440
SALES OFFICES AND SERVICE CENTERS IN MAJOR CITIES THROUGHOUT THE WORLD

LITHO IN U.S.A.

CONTROL DATA CORPORATION